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Sustainable Mobility and Intermodality
Promoting Competitive and Sustainable Growth

Galileo Overall Architecture Definition

Executive Summary

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ISSUE	***DATE***	***§ : CHANGE RECORD***	***AUTHOR***
1	13/10/00	First issue	S. Loddo
2	10/11/00	Consolidated inputs after PM5	S. Loddo
3	21/11/00	Complementary inputs	S. Loddo
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5	27/11/00	Complementary inputs	S. Loddo
6	08/12/00	Draft final issue	S. Loddo

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LIST OF ACRONYMS

AI	Accuracy and Integrity service
AIT	Assembly, Integration and Test
AOC	Advanced Operational Capability
BIPM	Bureau International des Poids et Mesures
C/A	Coarse Acquisition
CAS	Controlled Access Service
CCF	Central Control Facility
COSPAS	COsmicheskaya Sistemya Poiska Avariynich Sudov (Space System for the Search of vessel in distress)
CPF	Central Processing Facility (EGNOS)
CRC	Cyclic Redundancy Check
CSS	Comparative System Study
CUI	Control Uplink Interface
DAB	Digital Audio Broadcast
DGRS	Differential Galileo Reference Station
DME	Distance Measurement Equipment
EC	European Commission
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay Service
EM	Engineering Model
ESA	European Space Agency
FM	Flight Model
FOC	Final Operational Capability
Galileo	European Satellite Navigation System
GalileoSat	Satellite constellation and associated Ground Segment
GAN	Global Area Network
GAS	Governmental Access Service
GAST	Galileo Architecture Support Team
GBAS	Ground Based Augmentation System
GCPF	Global Check Processing Facility
GEO	Geostationary Earth Orbit
GIC	Ground Integrity Channel
GIPF	Global Integrity Processing Facility
GLONASS	GLObal Navigation Satellite System
GME	Galileo Management Entity
GMF	Global Monitoring Facility
GMS	Global Monitoring Station
GNCC	Global Navigation Control Centre
GNCF	Global Navigation Control Facility
GNSS	Global Navigation Satellite Service
GOC	Galileo Operating Company
GPS	Global Positioning System
GSF	Galileo Support Facility
GSSF	Galileo System Simulation Facility
GST	Galileo System Time
GUI	Global Up-Link Interface
HI	High Integrity service
ICAO	International Civil Aviation Organisation
ICD	Interface Control Document

IF	Integrity Flag
ILS	Integrated Logistic Support
IMO	International Maritime Organisation
IOC	Initial Operational Capability
IOV	In Orbit Validation
IPR	Intellectual Proprietary Right
IRR	Investment Return Ratio
ITU	International Telecommunication Union
GKGF	Global Key Generation Facility
LEO	Low Earth Orbit
LEOP	Launch and Early Orbit Phase
LIM	Local Integrity Monitor
LORAN-C	Long-range Air Navigation (3rd generation)
LUT	Local User Terminal (COSPAS-SARSAT context)
MCC	Mission Control Centre (SAR context)
MEO	Medium Earth Orbit
MEO LUT	MEO Local User Terminal (SAR context)
MMI	Man Machine Interface
NA	Not Applicable
NLES	Navigation Land Earth Station (EGNOS)
NMT	Not Meeting Target
NPA	Non Precision Approach
OAS	Open Access Service
OSPF	Orbit and Synchronisation Processing Facility
OTAR	Over The Air Rekeying
P/F	Platform
PFM	ProtoFlight Model
PL	PseudoLite
P/L	Payload
PPP	Public Private Partnership
PVT	Position, Velocity and Time
RAIM	Receiver Autonomous Integrity Monitoring
RAMS	Reliability, Availability, Maintainability, Safety
RAN	Regional Area Network
RCC	Rescue Co-ordination Centre
RCPF	Regional Check Processing Facility
RD	Reference Document
RF	Radio Frequency
RIMS	Ranging and Integrity Monitoring Station (EGNOS)
RIPF	Regional Integrity Processing Facility
RMS	Regional Monitoring Station
RMT	Risk Management Team
RNCC	Regional Navigation Control Centre
RNCF	Regional Navigation Control Facility
RNSS	Radio Navigation Satellite Service
RT	Range and Timing service
RTK	Real Time Kinematic
RUI	Regional Up-Link Interface
SAR	Search And Rescue
SARSAT	Search And Rescue Satellite Aided Tracking
SAS	Safety of life Application Service
SBAS	Satellite Based Augmentation System

SC	Service Centre
SCC	Satellite Control Centre
SCF	Satellite Control Facility
SIS	Signal In Space
SISA	Signal In Space Accuracy
SMCC	SAR Mission Control Centre
SNF	Satellite Navigation Frame
SNR	Signal to Noise Ratio
SOL	Safety Of Life
SPS	Standard Positioning Signal
SRC	Square root Raised Cosine
SUI	SAR Uplink Interface
SV	Space Vehicle
TAI	Temps Atomique International
TBC	To Be Confirmed
TBD	To Be Defined
TC	TeleCommand
TCAR	Three CARrier
TM	TeleMetry
TTA	Time To Alarm
TT&C	Telemetry, Tracking and Command
TTFF	Time To First Fix
UDRE	User Differential Range Error
UERE	User Equivalent Range Error
UHF	Ultra High Frequency
ULF	UpLink Facility
ULS	Up-Link Station
UMTS	Universal Mobile Telecommunication System
URE	User Range Error
USF	Uplink Scheduling Facility
UTC (BIPM)	Universal Time Co-ordination (Bureau International des Poids et Mesures)
UTC (k)	Universal Time Co-ordination (where k is an internationally recognised UTC laboratory)
UTC (USNO)	Universal Time Co-ordination (United States Naval Observatory)
VHF	Very High Frequency
WRC	World Radio Conference

1 SCOPE

Galileo is a satellite navigation system which has been studied by the European Space Agency and the European Commission for several years. The related programme is now in its definition phase and a decision related to its effective implementation is expected by the European Transport Ministers Council in December 2000.

Galileo implementation responds to key societal needs related to the provision of location and time data to a large number of users.
Many sectors will benefit from Galileo services, improving mobility and therefore quality of life in everyday travel and providing safety and efficiency to many activities related to professional and safety of life/ security applications.

At community level, Galileo is a key element in Europe’s policy to provide trans-European and global networks.
In the economic area, Galileo is a means to develop in Europe the services related to navigation, which are estimated to become major market segments, and generate significant revenues. It will also support employment and maintain highly skilled jobs in Europe.
From a strategic point of view, Galileo will bring independence to Europe in a domain mainly dominated by the United States with GPS.

The objective of this document is to provide the main outcomes of a study performed for the European Commission during the year 2000 (called GALA) and related to Galileo overall architecture definition.
The proposed Galileo architecture is based on an exhaustive analysis of potential applications needs, the derivation of system requirements and the consolidation of major system technical trade-offs in order to optimise the allocation of functions and performances among Galileo components.
GALA study also covers the design of Galileo signals, in line with the decisions of World Radio Conference 2000 which allocated additional spectrum to satellite navigation services.
A preliminary definition of Galileo components (global, regional, local) and of the user and support segments has been performed as well as the derivation of main programmatic elements for Galileo implementation (development plan, cost assessment, revenue opportunities, cost/ benefit analyses).
Furthermore several pilot projects have been defined in order to prepare the early demonstrations of Galileo related applications.

This document first presents the mission requirements and the definition of services to be provided by Galileo.
The key system level concepts or solutions proposed for Galileo are then described as well as the overall architecture definition, including the main components and important features (integration of EGNOS, interface with Search and Rescue mission).
The development and validation concept is presented together with an overall cost presentation and benefit analyses.
Main outcomes of the study are finally recalled together with recommendations for next phases of the programme.

2 MISSION REQUIREMENTS AND SERVICE DEFINITION

2.1 REQUIREMENTS DERIVED FROM USER NEEDS AND COMPETITION ANALYSIS

2.1.1 Introduction

The market for Galileo services has been analysed by identifying relevant applications and for each of these applications by:

- determining the user requirements,
- producing market size estimates (i.e. number of terminals),
- determining the acceptable user charges and estimated revenue.

The estimation of market size was based upon a bottom up approach where the total size and revenues were obtained by the aggregation of size and revenue details of individual applications. Each application was mapped on to one of four proposed navigation services. The market size and gross revenue estimates were also broken down by service type.

The process of defining applications and assessing user requirements and market size was carried out using data gathered from a number of sources. Market Specialists used their existing knowledge, previous reports and information acquired through interviews with potential users, representative bodies and other experts. A Core Team undertook an extensive review of the information provided by the market specialists. This review involved expert interpretation of the data and a thorough validation process.

2.1.2 User needs

Data has been collected about the technical and non-technical aspects of the user needs of 92 applications found on a very wide variety of platforms, location and environments. In particular, such technical parameters as accuracy, integrity (risk, time to alarm, alarm threshold), availability, operating environment and coverage were addressed. This knowledge has been used to define a number of navigation services that collectively satisfy the majority of the applications addressed. The following sub-sections discuss the user needs on an application by application basis, each application being afforded an equal weight.

2.1.2.1 Accuracy, Integrity and availability

Figure 2.1.2-a presents the accuracy performance requirements of both the complete set of 92 applications and a sub-set of key applications that have been defined as having a high priority. It can be seen that about 50% of all applications can accept a position accuracy (95% horizontal or vertical) of 3 m or more and 1 m accuracy is sufficient for about 80% of all applications studied.

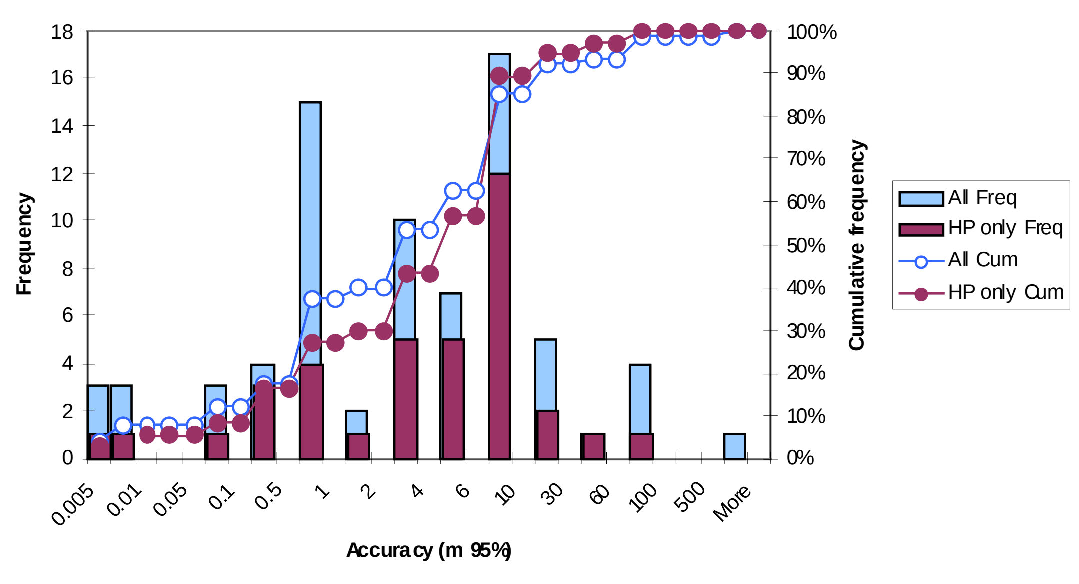


Figure 2.1.2-a: Distribution of accuracy requirements

The availability requirements are mapped against the accuracy requirements on the scatter diagram shown in Figure 2.1.2-b. As this data has been collected from the users, the availability parameter includes the effects of local environment. About 90% of applications require an availability of 99.0% or better and about 47% require an availability of in excess of 99.8%. In general, transport based applications are more demanding in terms of availability.

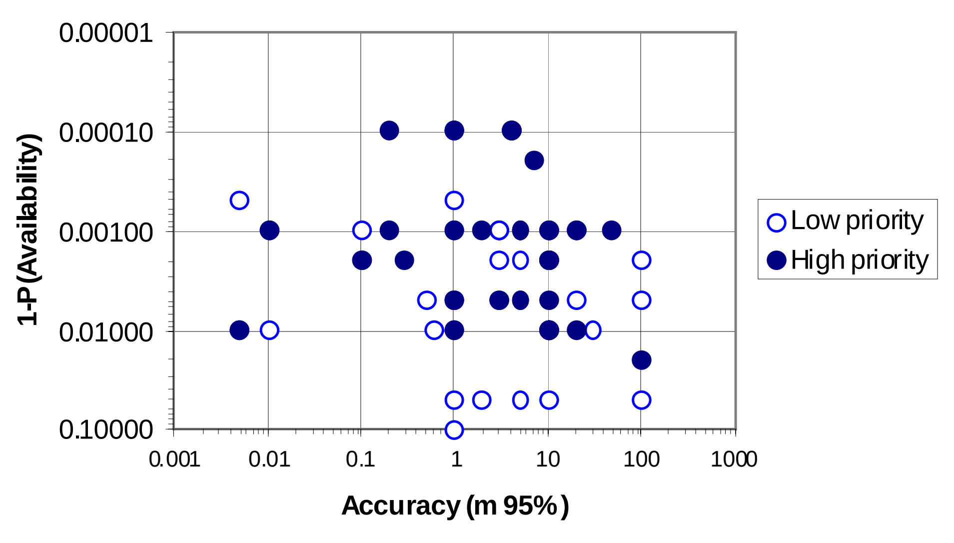


Figure 2.1.2-b: Scatter diagram of availability versus accuracy

A similar scatter diagram presents the data gathered on integrity factor. This is shown in Figure 2.1.2-c. It can be seen that a minimum integrity risk of 1x10^{-3} is needed even by mass market type applications and that the more demanding transport applications demand integrity risk factors in the range 1x10^{-6} to 1x10^{-9}.

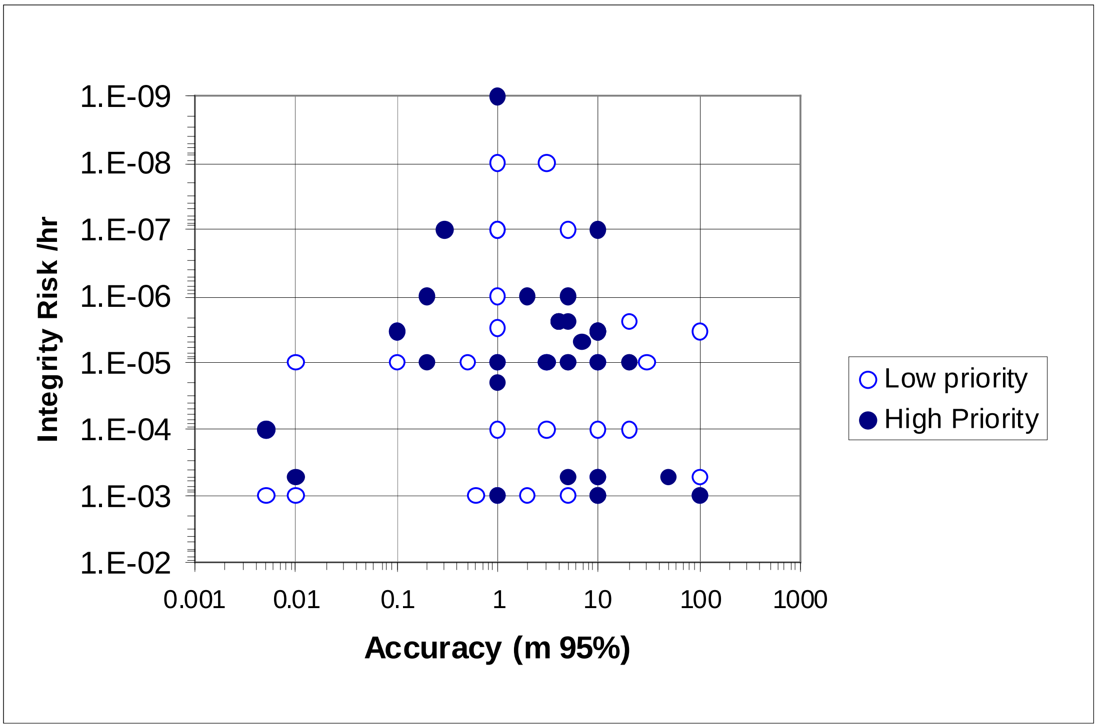


Figure 2.1.2-c: Scatter diagram of integrity risk versus accuracy.

It should be noted that integrity is a new concept to most of the applications addressed and the precise quantification of integrity performance is difficult. In the case of many applications, the integrity parameters have been selected as a result of a qualitative assessment of the risk. This clearly falls short of full quantitative assessment by risk analysis.

2.1.2.2 Other requirements

As many applications are associated with road vehicle and the person, a significant number of applications are expected to operate with limited sky visibility or sometimes to encounter conditions without sky visibility. Two key applications that need to operate without clear sky visibility are *location based communications services* and *lone worker protection*.

In some applications, non-technical parameters such as price are perceived as having a greater significance, this is particularly the case in mass market applications such as *location based communications services*, *personal outdoor recreation and driver services* which are more sensitive to equipment price than accuracy performance. The demands for signal robustness in the presence of intentional and un-intentional interference is essentially stemming from safety of life services.

2.1.3 Navigation Services

2.1.3.1 User requirements driven service definition

An assessment of the wide range of user performance requirements has identified the need for a number of navigation services:

- PVT (Position, Velocity and Timing Service) – a basic service for the mass market which provides real-time 3D positioning, velocity information and timing information in all parts of the world. Equivalent or superior to the SPS to be provided by modernised GPS.
- AI (Accuracy and Integrity service) - meets the needs of a) business or public services which require an accurate and reliable service for productivity reasons, b) the less demanding safety related applications. More than matches the performance and capability of current augmentation services.
- HI (High Integrity service) - fulfils the needs of safety critical applications by meeting demanding performance criteria, combined with long term guarantees of service provision.
- RT (Range and Timing Service) - meets the needs of knowledgeable professionals who need, either i) very precise ranging, or ii) precise positioning, or iii) precise timing signals. These products address the needs of niche markets including surveying, meteorological forecasting and time calibration.

These service definitions have been driven entirely by the user needs and must therefore be differentiated from the offered services derived from the system architecture (see chapter 2.4 for the latter ones). The details of each service are summarised in Table 2.1.3-a overleaf.
The service definitions shown in Table 2.1.3-a have been derived entirely from a consideration of the requirements for the technical parameters. However, it should be noted that a large number of applications consider non-technical issues to be a more important service discriminator. The non-technical discriminators identified are:

- Service guarantees,
- Legal liability,
- Traceability and auditability of past performance,
- Contractual and operational transparency,
- Certificatability of the SIS,
- Equipment standards and type approvability of user equipment,
- Interoperability with GPS,
- Integrated service provision.

2.1.3.2 Application to navigation service mapping

The four key performance levels contained within the service definition have been optimised to best meet the weighted needs of the 92 application addressed. Sixty three of these applications are well matched, while 13 are partially matched. Among the balance of 7 applications which are not well served, only two of them, namely *train control* and *harbour docking*, are high priority applications. It may be the case that mismatched performance requirements are best addressed by intensive use of hybrid sensors, specialised local augmentation or other navigation systems.

The applications mapped on to the RT service appear to be fragmented between precision survey, timing and atmospheric and ionospheric monitoring applications. Within the precision surveying community, there is a need for a long range real time kinematic (RTK) service provided that clear economic and operation advantages accrue.

Service	**Summary Description**	**Service Options**	**Accuracy (m 95%)**	**Availability %**	**Integrity**		**Contin-uity**	**Timing Accuracy (95%)**	**Resistance to interference**	**Scenarios for user access and service guarantees**
					Risk/hr	**TTA (s) see text**	**Risk/hr**	**(nS relative to UTC)**		
PVT	A basic service for the mass market which provides real-time 3D positioning, velocity information and timing information in all parts of the world. Equivalent or superior to the SPS to be provided by modernised GPS. Use of other sensors for a few applications.	PVT1: low cost terminal (single frequency).	15	99	$<10^{-4}$	30-60	NA	100	Low	Open access service for general public use is assumed. No guarantees of service performance would be offered, with the possibility that the service may be degraded in times of tension or war.
		PVT2: moderate accuracy service (dual frequency terminal or SBAS Iono corrections).	6	99	$<10^{-4}$	30	NA	100	Low	
AI	A service to provide increased accuracy and integrity to meet the needs of a) business or public services which require an accurate and reliable service for commercial reasons, b) less demanding SOL users. More than matches the performance and capability of current augmentation services.	AI1: high accuracy service (2 frequency terminal).	2	99.9	10^{-6}	10	TBD	100	Medium	Potential to attract users by providing guarantees of long term availability, by being transparent and responsive over service performances (performance guarantees). Ability to collect service revenue. Service may be degraded in times of war.
		AI2: very high accuracy over a local area (2 frequency terminal + augmentation)	0.2	99.9	10^{-5}	10	TBD	100	Medium	
HI	Offers high integrity and availability. Fulfils the needs of safety critical applications by meeting demanding performance criteria, combined with long term guarantees of service provision.	2/3 frequency terminal (certified)	2	99.99	10^{-8}	6	10^{-7} - 10^{-8}	100	High	Service provider will have liabilities linked to the service performance and long term continuity (may require government sponsorship). Ability to collect revenue.
RT	Meets the needs of specialist and knowledgeable professional who need either very precise ranging, or precise positioning, or precise timing signals. Often niche markets, include surveying, meteorological forecasting, and time calibration.	Specialised precision terminal (2/3 frequencies). This service could be split to provide 0.1m (RT1) and 0.005 (RT2) perhaps using local RTK.	0.01	99.9	10^{-5}	20	NA	10	Low	Revenue recovery may be through augmentations or bundled added value information services or perhaps through equipment sales. Service may be degraded in times of war.

Table 2.1.3-a: User driven service definitions

2.1.3.3 Comparison between the user and architecture driven definitions

The service definitions derived from an implementation (architecture) driven study (see also chapter 2.4) are compared with the user driven service definitions discussed above in Figure 2.1.3-a. To allow for aspects such as access control and signal robustness, PVT should be associated with the OAS family of services, AI with CAS and HI with SAS. Whilst there is a reasonable degree of correlation between the two sets of service definitions, a number of mis-matches have been identified. In particular, mis-matches in integrity and availability levels are apparent. Furthermore, there appears to be no equivalent of the AI-2 service.

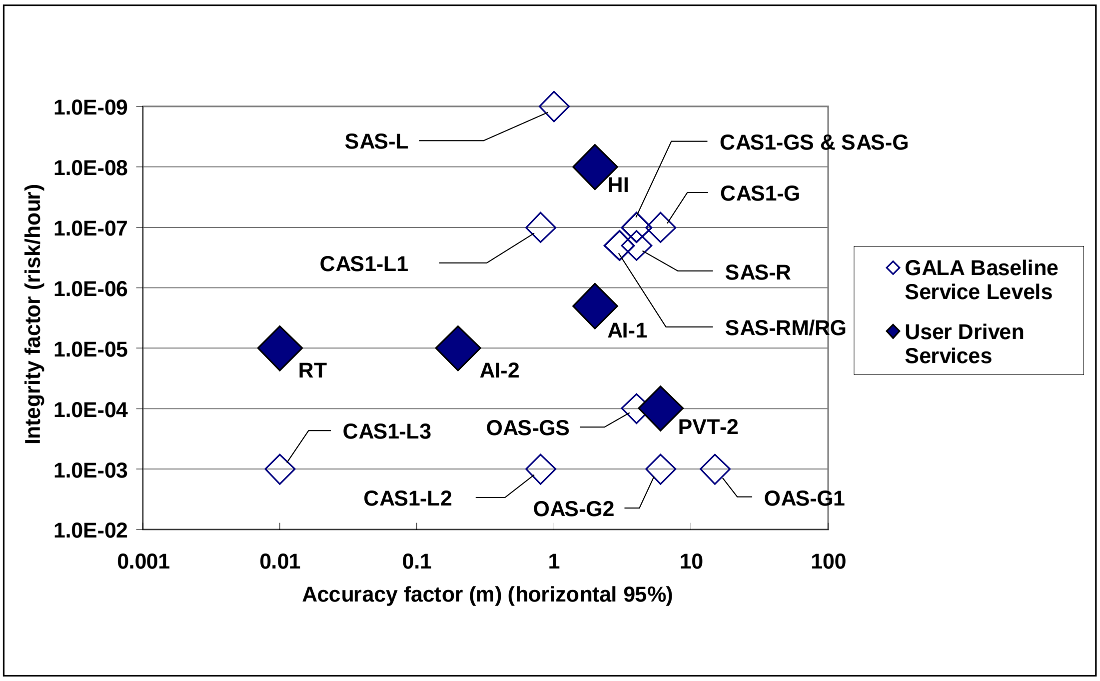


Figure 2.1.3-a: Comparison of user and architecture driven service definitions

2.1.4 Market size and revenue

2.1.4.1 Market size

A bottom up, application by application estimate of the Galileo market size for the period 2010 to 2020 has been made. It has been derived by first estimating the addressable market size over the period 2000 to 2020 for a defined set of geographical regions. These addressable market size figures are factored by GNSS penetration and Galileo market share ratios to arrive at the final estimated Galileo market size. The economic scenarios include a pessimistic case, most likely case and an optimistic case. The market size results are summarised as follows.

Total Galileo market size. The most likely value of market size in 2015 is just over 410 million units (users/terminals). This rises to 745 million in 2020 (see Figure 2.1.4-a).

Breakdown by service. The PVT service has, by far, the largest market, being 99% of the total Galileo market size (i.e. approximately 404 million users/terminals in 2015). This compares with approximately 5.5 million for the next largest service, AI. On this scale, the HI and RT services do not register being about only 70,000 users/terminals each.

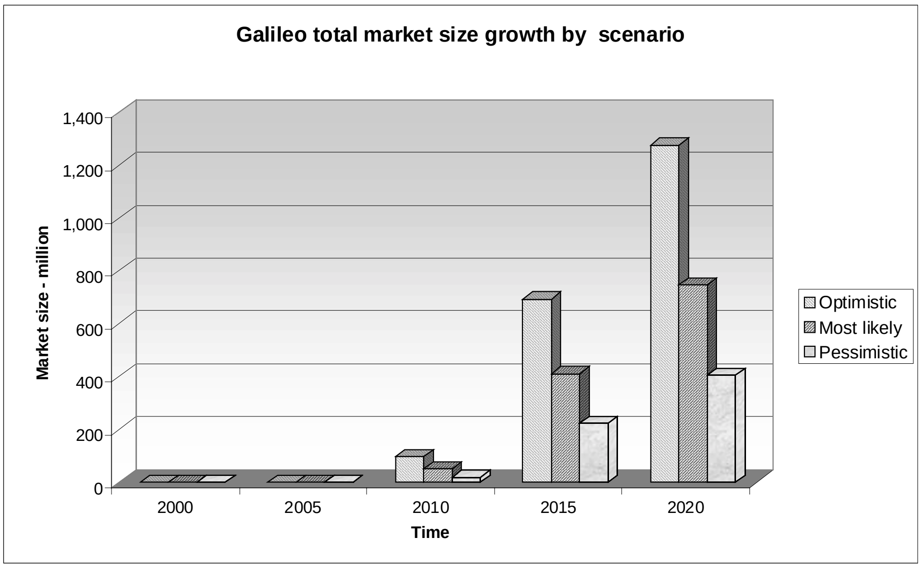


Figure 2.1.4-a: Market size growth by scenario

Breakdown by application. Two applications dominate the market size representing between them 96% of the total market of 410 million users/terminals in 2015. These applications are:

- *location based communications* (i.e. mobile phone based location services) with 336 million users/terminals under the most likely scenario in 2015,
- *driver services* (i.e. route guidance, information services, emergency call, theft and recovery for all vehicle categories) with 56 million (most likely in 2015).

In the case of the *location based communication service* application, the Galileo share (in 2015, most likely scenario) is 16% of the addressable market size and the GNSS penetrated market is 38% of the addressable market. In 2020 these values rise to 20% and 45% respectively as the proportion of GNSS fitted phones in the world rises.

Breakdown by region. The region with the largest share of the Galileo market in 2015 is the Pacific Rim with 169 million. This is followed by Europe at 125 million and North America at 46 million. This market size distribution is dominated by the size of the *location-based communications* application that has a large forecast Galileo market in the Pacific Rim region. This is caused by the underlying size of the addressable market which in 2015 is forecast to be 593 million in the Pacific Rim region compared with only 294 million in Europe.

2.1.4.2 Revenue

The revenues attributable to the Galileo system have been estimated in terms of year 2000 Euro. This revenue has been estimated in terms of a *gross* revenue and a *net* revenue. The gross revenue can be considered as an indication of the level of economic activity which could be generated by the system a. The net revenue attempts to include only those parts of the gross revenue which are directly attributable to the Galileo navigation products and services. These estimates have again been produced using a bottom-up approach whereby product and service price have been estimated for each application. As these estimates are at the customer supplier interface point in the supply chain, a subset of it is estimated to flow to the Galileo Operating Company, to be estimated on an application per application basis.

Total Revenue. The forecast gross combined annual revenue (i.e. the global total) in 2015 (most likely) is 22.2 B Euro. However, the net component of this is considerably smaller: only 3.2 B Euro (14%) (see Figure 2.1.4-b).

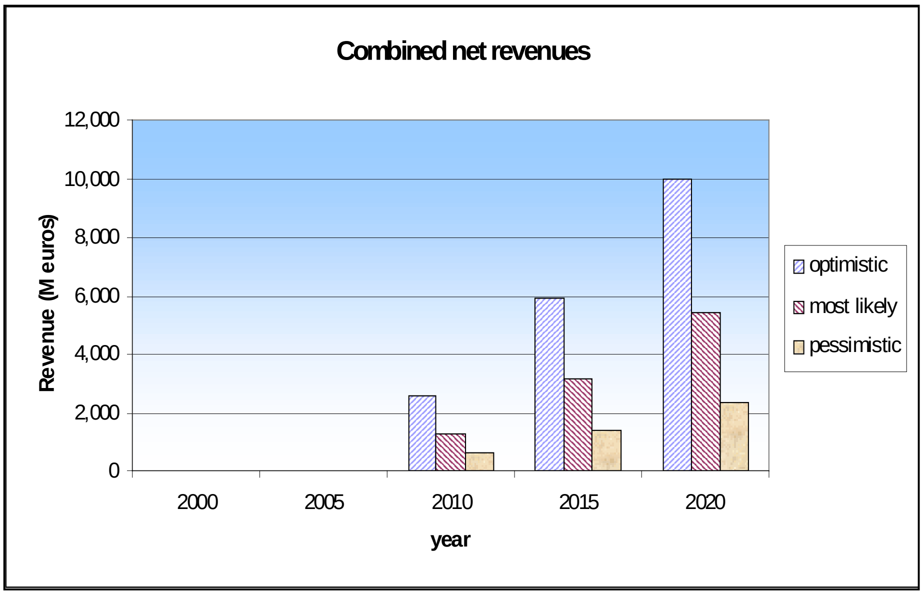


Figure 2.1.4-b: Total net revenue by scenarios

Gross Revenue by Service. PVT service applications make up the largest part of this total gross revenue with a share of 86% (18.9 B Euro) followed by AI applications with a 13% share (2.9 B Euro). The RT and HI services are considerably smaller with shares of only 0.95% and 0.43% respectively.

Net Revenue by Service. The PVT share of total net revenue is smaller but still the largest at 59% (1.875 B Euro); however, the other services have larger shares: AI is 33% (1.043 B Euro), RT is 6% (182 M Euro) and HI is 2% (71 M Euro).

Gross Revenue by top applications. The top 5 applications contribute 94% of the gross revenue. The top 2 applications alone, *driver services* (12.6 B Euro) and *location based communication services* (4.6 B Euro) together are responsible for 80% of the total revenue; they are both PVT service applications. However, the net revenue component of the top 2 applications above is only 50% (1.6 B Euro).

Revenue of the remaining applications. These smaller applications provide a gross revenue of 1.43 B Euro (6% of the total) and a net revenue of 837 M Euro (26% of the total).

Product versus Service revenue. In 2015 (most likely values) the gross product revenue (13.2 B Euro) is 60% of the total gross revenue. However, in 2020, this ratio is reversed with the total service revenue (27.3 B Euro) being 64% of the total. This is to be expected because the service revenue is collected from a growing population of customers, whereas the purchase revenue is collected only from new sales.

2.2 DESIGN REQUIREMENTS

2.2.1 Candidate services

The Galileo system will provide a word-wide (global) radio-electrical service allowing users equipped with a dedicated receiver to get their continuous and accurate real-time 3-D position and velocity information (according to ITRF 96 geodetic reference) as well as a Galileo reference time (according to Galileo System Time Scale). This global service will be possibly improved (accuracy, availability, integrity, etc.) in regional and local areas.

As a result of an iteration process with the market analysis and system definition, the Galileo system will provide, as a baseline, four levels of navigation and timing services :

1. Open Access Service called OAS for Mass Market applications,
2. Controlled Access Service, level 1 called CAS 1 for Professional Market applications,
3. Controlled Access Service, level 2 called CAS 2-SAS for Safety of Life applications,
4. Controlled Access Service, level 2 called CAS 2-GAS for Governmental applications,

The differences between OAS, CAS1 and CAS2 services are described in section 2.4. It shall be noted that only these four navigation services are foreseen, the other sub-levels identified in this section represent the conditions under which the performances are achieved : environment, hybridisation or combination with external systems or sensors.

A Search and Rescue Service is also proposed as a baseline service of Galileo system in the frame of COSPAS-SARSAT follow-up mission : it is described in Section 2.5.

In order to satisfy user needs, these services will be supplemented by a navigation-related communication service. The navigation-related communication service is related to navigation (or positioning) data or related information (such as traffic information in the considered area).

The baseline approach in GALA is that this service is performed through the use of external communication systems such as for example GSM/UMTS or INMARSAT-like satellites.

An option has also been identified for considering the possibility to implement on board Galileo satellites a dedicated telecommunication payload for broadcatching (from the users to the service centres) and broadcasting (from the user centres to the users) short messages. This issue is described in Section 2.6.

2.2.2 Security policy

The security aspects are a key driver for Galileo service definition : they address in particular the frequency allocations and the cryptology approaches.

It is to be recalled that no formal security policy has been derived yet by the Galileo System Security Board. The following section therefore presents the rationale/ assumptions related to the security policy considered by GALA.

2.2.2.1 Rationale for a dedicated service

From a security point of view, the provision of world-wide positioning services may cause a major “misuse threat” if they can be used for unfriendly purposes. In addition, the access to satellite navigation services will become more and more easy, due to the future very high number of low cost receivers, providing very accurate positioning information.

The solution assumed to be implemented by national security authorities is to intentionally jam the navigation signals that represent such a threat, on a local basis and during crisis and war periods.

This solution would be necessary for security reasons, but would have dramatic impacts on all the foreseen applications relying on such signals. Therefore, the approach is to avoid the intentional jamming for the highly critical applications which do not represent a misuse threat. These applications, among which civil aviation, governmental civil and military applications, and other critical applications like network synchronisation for secured data transfers, would be offered a dedicated service, avoiding the necessity of jamming and therefore guarantying the availability in crisis and war periods. The encryption of the signals is the technical means to dedicate this service to the intended users.

2.2.2.2 Access management

The access management of an encrypted service can be performed geographically, users being authorised or denied depending on their geographical location, by group of users or individually. The geographical access management allows to accurately deny a conflict area to all critical civil users (civil aviation, maritime, etc.) : this would prevent anybody, including adverse parties involved in the conflict, from the need to jam such signals intentionally.

This provides full protection of the SAS, dedicated to such critical civil users, and would be possible if SAS and GAS services occupy distinct frequency bands. Such a protection will not be possible for OAS, since its users are not known at all, therefore representing the formerly described misuse threat. This situation drives the need for separation of OAS and SAS frequency bands.

2.2.2.3 Encryption of SAS ranging signals

The encryption of SAS ranging signals, as a consequence of the security policy, needs to be carefully addressed, due to the consequences on safety, certification, standardisation and on the operational procedures to be implemented for ensuring an adequate management of SAS users.

Regarding safety aspects, the possible sources of failures have been investigated, which range from key mismatches to wrong identification of users or user groups as examples. No apparent unfeasibility has been identified.

With respect to certification, it has been assessed that public encryption algorithms are better suited for civil aviation, since the visibility on algorithms is likely to be required by the certification authority and the standardisation process.

As mentioned in the rationale, the objective being to avoid intentional jamming of SAS signals from security authorities and adverse parties, it is needed to guaranty that the service is used for its intended purposes. Procedures will therefore be needed to regularly check that SAS users are the intended ones.

The operational constraints on SAS users need also to be addressed carefully, to avoid work load or heavy constraints and the possibility of wrong keying. Several solutions have been investigated, the basic current concept being that secret elements in the user terminal would be segregated to a “PC-MCIA”-type card, which could be physically dissociated from the terminal itself in order to ease the maintenance of user terminal hardware and not require any secret element from the user himself.

2.2.3 EGNOS

The proposed integration of EGNOS in Galileo, in terms of objectives, services to be provided, architecture and programmatic aspects are detailed in Section 4.6.

The integration scheme has been derived in the following steps:

- Determine the optimal Galileo architecture to fulfil the identified user needs, on the long term in order to ensure its future viability,
- Derive the optimal integration of EGNOS with respect to the identified objectives of this integration.

The integration of EGNOS has to avoid any impact on the current EGNOS AOC development as it is currently defined : operational capability in 2004 for a 15 years lifetime.

This would guaranty that the intended EGNOS services are provided on time to the users. This will also allow to achieve a complete development cycle of a complex system, which is of paramount importance for the credibility of Europe in the development of critical navigation systems.

The necessary evolutions of EGNOS within Galileo are foreseen in one step, and are proposed to accommodate GPS evolutions – provision of the additional civil aviation signal on L5 – that will occur in a similar time frame as Galileo.

The evolution of GPS, which will broadcast dual frequency signals for civil aviation (L1 and L5) implies to provide a new service for users of GPS. It can be anticipated that the other SBAS systems will also follow the GPS evolutions, therefore proposing to implement a regional GEO based service. The GPS integrity services provided through the GEO payload SIS are described in Section 4.6 and related performances are summarised in section 2.4.

2.2.4 GALILEO integrity and certification/standardisation

Galileo will provide a set of services that include the provision of integrity information concerning Galileo satellites. This information is broadcast within Galileo signal in space from a subset of MEO satellites, on a global (world-wide) basis.

In addition, regional services (outside Europe) can be provided through the implementation of regional components, based on integrity monitoring and control ground segments. The resulting integrity messages are sent to Galileo global component for broadcast within a reserved slot in the Galileo signal in space.

All identified Galileo services assume that the integrity information is protected for security and commercial reasons, therefore being encrypted, and reserved for authorised users only.

It shall be highlighted that even if Galileo services are based, in particular for integrity provision, on an architecture slightly different from the GNSS1 concepts, certification and standardisation concepts are the same as for EGNOS system.

2.2.5 GPS assumptions

Galileo services may be considered, in some instances, as competing with GPS services. It is therefore required to define Galileo services with key differentiators for the users or the intermediate service providers, when Galileo is used on a stand-alone basis.

It is also clear that a lot of applications will take benefit of an optimised combination of Galileo and GPS signals at user terminal level. This requires the implementation of a certain level of interoperability between the two systems. This appears particularly predictable in mass markets where users will try to take a maximum benefit of free of charge services.

GPS assumptions are therefore needed when defining the Galileo services, as they represent the conditions to consider for defining the performances of hybrid Galileo plus GPS services.
The GPS interoperability requirement also adds a constraint on Galileo signal definition, as the selected frequency plan and code structure have to be compatible to a certain extent with current and future GPS civil signals (Standard Positioning Signals).

2.2.5.1 Assumptions

Around 2008, the GPS system will be different from what it is today. The current GPS satellites (from block IIA and block IIR) will be replaced by the GPS block IIF and later GPS block III satellites. These satellites are the next generation satellites and they will be launched from 2005 and 2008 respectively. Block IIF and block III are assumed to provide significant enhancements over the IIA and IIR, noting that some modified IIR satellites (including L2 C/A code) will be launched from 2003. The design enhancement will lead to a lower URE and lower positioning error. It concerns:

- Better performance of the frequency standards,
- Reduction in the age of data of the broadcast navigation message to less than 3 hours,
- Provision for C/A code and P-code on L2,
- Increased user received power level,
- Provision of a third civilian signal in L5 aeronautical radio-navigation band.

The scheduled date for operational capability of GPS system with block IIF and block III satellites is around year 2016.

2.2.5.2 Dual mode Galileo/GPS receiver

For applications that do not need total independence or guaranty of service, users can take benefit of a combination of GPS signals with Galileo signals, and therefore improve the visibility geometry.
This combination is not foreseen to be a comparison of the computed PVT (Position, Velocity and Timing) data derived from the two systems. Indeed, the objective is to consider all satellites as if there was only one system, in a transparent way. The relative information between both systems including the delta between geodetic and timing references being transmitted within Galileo navigation message.
Some applications will require to combine Galileo, GPS and GLONASS signals but the market foreseen is very small and therefore it appears not to be a real driver to consider this kind of combination when defining Galileo system.
There will also be some possible combination schemes related to the integrity broadcast by Galileo and GPS overlay systems.

2.3 LEGAL AND INSTITUTIONAL REQUIREMENTS

A key differentiator of Galileo controlled access service with respect to GPS system is that the Galileo operator will provide a guaranty of service to service providers or final users.

2.3.1 Technical and legal definition

The guaranty of service concerns the complete service over a given period, that is to be defined and may depend on the service and on the users. Technically, this guaranty of service is provided first by the integrity information which ensures to the user that the system is operating well (when it is in a nominal status) and provides alarms (in case of failures). In addition, as the availability of the service is to be controlled, the guaranty will directly impact the required reliability of the system as well as the replacement strategy (with a priori in orbit spare satellites for reducing the mean time between failures).

From a legal point of view, this notion of guaranty of service is relying on mechanisms implemented a priori and a posteriori to prevent, inform (off-line), alert (on-line) or compensate failure, disruption or provision of a service not meeting all of its specifications.
These mechanisms include:

- certification, to guarantee that all risks have been a priori controlled,
- licensing, to guarantee that the service is used in accordance with its intended uses,
- a guarantor, to a posteriori take the responsibility for abnormal events. This implies to set up a precise institutional and organisational framework with defined roles, responsibilities and liabilities. To this aim, due consideration has to be granted to a “management” functional analysis and to an “operation” functional analysis.
- a compensation mechanism to reimburse damages,
- a “jurisdiction/recourse mechanism” to be able to claim for compensation

Each part of the service guaranty therefore implies to firstly interface with the technical definition of the service. The technical performances are the technical corollary of service guaranties and provide features for the availability of the signal.
It secondly implies to precisely define the application field of each clause of the legal definition – i.e. certification, licensing, responsibility, liability, compensation and jurisdiction.
It is thirdly necessary to associate contractual or conventional clauses and solutions to service failure, disruption or provision out of the specifications, due to the system, the user segment, the environment, the possible denials, etc.
It is lastly of high importance to enlighten actions to be achieved in the legal field due to technical, financial or safety studies and imperatives.

2.3.2 Certification and the international credibility of the system

The objective is to ensure that the provided service is delivered according to the relevant technical requirements or processes and to a defined binding procedure.
The main actions and recommendations are therefore to establish a certification entity for Galileo, and in parallel to start promote Galileo standardisation of the delivered services, under the auspices of international bodies (ICAO, IMO, ITU, etc.)
The European relevant authorities have to begin to build up certification procedures according to technical performances and existing certification process and entities. The main purposes is to enlighten the possible gaps in the certification processes due to the specificity of satellite navigation –i.e. the certification of a service.

As far as possible, it is nevertheless important to focus on the use of existing certification frameworks (e.g. for civil aviation applications) and to enlighten the likelihood of new certification procedures.

2.3.3 Service guaranty, control access and the need to limit risks

Guaranty of service involves the responsibility and perhaps liability of the service guarantor. This is the assumed main differentiator from the American GPS or the Galileo OAS. In both cases, there is no technical performance and availability guaranty. It is moreover of main importance to enlighten and define the legal means to exclude liability – i.e. the likelihood of liability waivers and disclaimers.

When guaranty of service is evoked and in order to limit the risk as much as possible, the guarantor shall be confident in the use and users of the provided services. On a legal and insurance point of view, “taking responsibility” is only possible when the risk is under control. This enlightens the need for a definition and legal qualification work on Galileo risks – i.e. catastrophic risks, major risks, etc.

The risk management and the increase of linked taken responsibility and liability are possible by controlling the access to the service. Controlled access services through licensing shall allow to limit the risks of misuses and therefore to increase the level of responsibility and liability the guarantor shall take. The main reason is that controlling the use of the service, which is not possible for OAS, limits the main risk – i.e. court actions introduced by unknown users for uncontrolled damages, and forum shopping.

2.3.4 The need for a strong guarantor for Galileo

A guarantor for Galileo implies to set up a precise and defined institutional and organisational framework for Galileo. The first task in this field is to embody States and the European Union with precise roles and responsibilities for satellite navigation in Europe and world-wide.

Moreover it is necessary to fix in a clear way the institutions, entities and companies, currently existing and to be established, peculiarly focusing on hosting country or countries, because it determines the positive law for the implementation of the entity or entities, legal personality, responsibilities, roles and compositions.

The ownership of the system is one of the most sensitive topics regarding Galileo. Furthermore international and European texts and regulations exist in the field of space asset ownership and linked rights and obligations, responsibility, registration and liability (in the 1972 Liability Convention sense). Ownership also deals with or is impacted by the identity of the owner, “nationality” (either domestic or European) of the system, the question of independence of the system through ownership. Ownership obviously enlightens a necessary IPR general agreement on essential concerns (patents, know how, etc.)

The owner of the asset will be submitted to the positive law of the hosting country. Procurement rules shall also be studied, granting a peculiar interest to the Agreement on Government Procurement. Lastly the possible system concession legal regime may have important consequences on the ownership legal regime.

From an organisational point of view, possible existing frameworks such as INMARSAT as amended, the European Environment Agency, the Arianespace model, the Spot Image model, INTELSAT scheme are relevant for Galileo. Parts of all those models show significant and profitable interests for the scenario retained for Galileo. The most interesting one for general organisation appears to be the INMARSAT framework.

The relationship among the different actors in Galileo will be embodied in precise identified legal links. But the legal qualification for each of those legal links is of main importance. One could be a Public Service Agreement, between the Galileo Agency and the Galileo System Operator. A Public Service or Public Market Concession can be agreed between the owner of the system and the operator of the system. Private law contracts will rule relationships between the service provider and the users. It is also of main interest to focus on the inventory of all other possible legal links that frame the Galileo service provision chain.

Organisational issues also deal with the control of the system. Depending on the legal personality of the involved institutions in the Galileo service provision chain, the control of the system can be public, private or shared. Advantages and drawbacks of all alternatives are to be carefully studied.

2.3.5 Compensation and the viability of the system

The compensation may be limited or unlimited. It can also be established through contractual or conventional clauses used as technical gap fillers in case of abnormal events. These clauses forecast for instance reparation or replacement within a certain period of time. Due to the specificity of Galileo purpose – i.e. the provision of a service, the compensation clauses are to be totally innovative.

The compensation system shall forecast due guaranties for compensation payment such as the Agency, State or the settlement of a European or international Fund for damage compensation. If need be, mechanisms for fund recovery and criteria for using the compensation Fund are to be set up. Another solution is to guaranty the compensation payment through insurance and re-insurance mechanisms.

It is also necessary to enhance safety analyses and failure trees with financial scenarios linked to compensation, court action, etc.

2.3.6 Jurisdiction and possible relevant legal regimes

The service guaranty means that the claimant or the victim has prompt, available settlement of dispute frameworks, defining in particular means of proof and recording systems, the likelihood of claims, the definition of the parties, available recourse mechanisms and a jurisdictional system available to introduce its claim.

But as long as service guaranty is to be ensured, it is also necessary to take into account the defending capacity of the responsible or liable entity (ies), through as far as possible the limitation of the potential claimants to known users, the limitation of the forum shopping risks, the limitation of the liability/compensation amount risks and the definition of the possible recourse actions for the liable entity.

According to the different enlightened services, several legal regimes apply. The main criteria for legal regime definition are the user community and associated peculiar legal environment, the legal personality of the service provider (s) and the technical service guaranties.

The different possible positive legal regimes are:

- a contractual limited liability regime based on commercial objectives. This legal framework enlightens the issue of quasi-contractual liability and necessary precise limits to it,
- an extra-contractual liability regime (civil liability), either limited or not, based on common law obligations. States / Inter Governmental Organisations liabilities are to be carefully taken into account through for instance the joint and several liability mechanisms or the use of substitution action mechanisms as well as the qualification of the liability regime - i.e. either absolute or fault liability,
- tort liability in any case when tort law applies.

2.4 NAVIGATION SERVICES AND SYSTEM PERFORMANCES

This section addresses the description of each navigation service and the summary of performances at user terminal level.

2.4.1 Open Access Service (OAS)

The Open Access Service (OAS) is defined for mass market applications and then shall provide by definition free of direct user charges access signals for positioning and timing. The Galileo OAS shall be accessible with the adequate receiver without authorisation.
As this market is already addressed by GPS SPS signals, the GALILEO OAS services shall match the expected performance of the GPS IIF or GPS III SPS and its evolutions.
As for GPS, the OAS service shall not provide an integrity information computed by the system. Indeed, the OAS service is not guaranteed and the quality of Galileo SIS can only be estimated by algorithm implemented at user terminal level (RAIM). The OAS service is never granted, especially in case of crisis or war. There is no liability from Galileo service provider on OAS services.
The OAS Service is defined in order to be compatible with low cost receiver designs, as European receiver manufacturers will face a real competition from GPS receiver manufacturers (mainly non European).
The OAS service shall be compatible with user terminals using one or two fixed frequencies : the choice of whether to use single or multiple frequency capability in a receiver is left to the user. A single frequency system is likely to be, at least initially, cheaper and smaller, and would be used in certain portable applications (such as the hand-held receiver market). A multiple frequency device may have uses where space and weight are not so much at a premium (such as in-car). The use of only one frequency will degrade slightly the accuracy performance as described in the table of service performance.

The OAS signals are unencrypted the proposed structure of which is defined in a public ICD.

The single and dual frequency OAS are global : delivered world-wide. They are respectively called **OAS-G1** (for Global 1 frequency) and **OAS-G2** (for Global 2 frequencies).
From a user point of view, it will be possible to combine Galileo OAS signals with signals from other systems in order to improve either the accuracy or the availability of a given level of accuracy. The choice of these systems will probably depend on the considered application but the following combinations are anticipated :

- Galileo OAS-G2 signals with GPS SPS signals (L1 and L5 for example) : this service is called **OAS-GS** (for OAS Global plus SPS signals),
- Galileo OAS-G2 signals with LORAN signals : this service is called **OAS-GL** (for OAS Global plus Loran signals), and is supposed to take benefit of better availability of LORAN signals in urban areas,
- Galileo OAS-G2 signals hybridised with other sensors already embarked by the user vehicle such as gyros, accelerometers, etc. signals : this service is called **OAS-GH** (for OAS Global plus Hybridisation), and is supposed to take benefit of better availability of hybridised sensors in urban areas (these sensors being better calibrated when Galileo SIS are available).

A combination with GSM-UMTS is also envisaged in particular for in-door navigation and will have to be defined when positioning techniques based on UMTS capability are better defined.

2.4.2 Controlled Access Service 1 (CAS1)

The Galileo Controlled Access Service 1 (CAS1) is defined for professional or scientist market applications which need a better service than OAS and are ready to pay for it. From a user point of view, different levels of performance improvement can be achieved based on the use of high data rate signals.

First, the CAS1 service is broadcasting on a global basis (world-wide) an integrity information that controls the quality status of CAS1 signals and sends an alarm to the user in case of problem in a very short delay (Time To Alarm in the range of 10 s). The CAS1 service will be guaranteed, if the user is using a CAS1 certified terminal under normal conditions, except in period of crisis or war. This notion of Service Level Agreement is a key performance differentiator with OAS (plus GPS) services even when combined with RAIM algorithm as, in the latter case, there is no formal liability from the Galileo Service provider. This Global service is called **CAS1-G**.

An alternative to this service consists in combining Galileo CAS1-G service with GPS SPS service and by also computing and distributing to users the integrity of GPS signals. This service is called **CAS1-GS** service (for Global and SPS).

The second main interest of CAS1 service deals with accuracy improvement. Differential corrections enhance the accuracy provided by the Galileo Global Component down to a metric level, by reducing (or removing) common (i.e. correlated) errors which occurred during the signal propagation. This is achieved by the broadcast to the user of the corrections computed by ground-based reference stations, namely Local Components. The broadcast information data are constituted by the differences obtained comparing simultaneous or near–simultaneous measurements performed by a reference station (located in a known position), with the expected values (based on the "a priori" known location). Such corrections are then transmitted in real-time to the users over the area of interest, that can extend from typically 10 to 50 km from the reference station.

Moreover, the Local Component can compute an Integrity information, and transmit it to the user within a Time To Alarm shorter than the one provided by the Global Component, as the information is typically broadcast locally by UHF-VHF links and not via the Galileo satellites. This local service is called **CAS1-L1**. The interest of an additional alternative consisting in broadcasting the local correction data via Galileo satellites (called **CAS1-L2**) is analysed but presents market limitations due to the limited number of areas that can be covered at a given point in time.

It shall be noted that the CAS1-L1 service can be proposed by external service providers that can develop their own reference stations and use the OAS signals as there is no need for global integrity information. This kind of service is aimed to be part of a package which would provide a value-added service by combining different types of information (location plus traffic information for road market for example). There will therefore be a competitive environment in this field and the viability of Galileo CAS1-L1 and CAS1-L2 will have to be demonstrated.

A third local service (called **CAS1-L3**) is proposed for users who require centimetre accuracy level or real-time kinematics. This service is based on the use of TCAR algorithms that require to process a third navigation signal. For commercial purposes, this third signal might be encrypted and then its access could be charged to this kind of users (construction and civil engineering, mining, geodesy, etc.). In fact, as a baseline, it is proposed not to encrypt this third frequency (there would then be three OAS signals). AS a matter of fact, as TCAR algorithms need differential corrections (which can be encrypted), CAS1-L3 service can still be considered as part of CAS1 local services.

However, it shall be noted that, by 2016, GPS system will provide three open access signals, free of charge and it will be difficult to sell this kind of service, even if the differential corrections needed for TCAR service are free. In this case, the service might become an OAS service called OAS-L3.

The Galileo CAS1 shall be restricted to paying users, with the adequate receiver. The CAS1 service shall be compatible with user terminals using two or three defined frequencies.

As a baseline, the CAS1 services are supposed to be based on OAS signals with encryption of data to be accessed by professional users (global or local integrity, local differential corrections, etc.) as part of the navigation message.
However, the overall viability of CAS1 service is not fully demonstrated as there are or will be, on the market, competitive and free of charge services. As noted above, with Galileo OAS signals plus, if needed, GPS SPS signals, the local service can be proposed by external service providers, and the integrity information can be computed at user terminal level : one could argue that users will reject paying for CAS1 service despite the Service Level Agreement.
Anyhow, as the integrity information shall be in any case provided for CAS2 services, the provision of global integrity for CAS1 signals will not result in a large extra cost on system development. It could be provided in any case, even if paying for this service turns to be not viable. Therefore an alternative consists in not encrypting the data and providing them free of charge as part of OAS services. In this case, there would be no more a CAS1 service but a more competitive OAS service (but no Galileo liability).
The choice for keeping or not a CAS1 service can be made later on during the development of the programme, when the market analysis is more mature. The only impact would be the development or not of encryption boards.
As fleet management is a key market for CAS1 service, professional users will require in particular to improve the availability of the service in non favourable environment such as urban areas. Therefore, the CAS1 services shall be defined in order to optimise the time to first fix (TTFF), in particular for reacquisition of SIS after shadowing effects due to building blockages. In addition, there is a need for combining, at user terminal level, CAS1 signals with other sensors (gyros, accelerometers, etc.) or systems (LORAN, GSM-UMTS, etc.).

2.4.3 Safety of life Access Service (SAS)

Safety of Life considerations are important for nearly all transport applications but also for many non-transport applications. There is no common definition of the term “Safety of Life Requirement” among different Safety of Life applications. Have been considered in this category the applications which, if performance of a navigation service is degraded or terminated without real time notice, could lead to having human lives being placed in danger.
The main driver for this service is the provision of a high integrity level of navigation data with optimised Alarm Limits and Times To Alarm. In addition, the SAS service shall be certified and related standards shall be defined and qualified.
The civil aviation community as well as the maritime community have produced clear performance requirements for the different phases of navigation, which have been considered for the SAS service definition. These requirements are slightly more stringent than OAS/ CAS1 ones.
The SAS performance shall be obtained by using the adequate certified dual-frequency receivers. The frequencies for SAS shall be Aeronautical Radio-Navigation Services frequencies.

As a baseline, it is proposed to encrypt the SAS signals. With encryption, the security policy (described in section 2.2.2) could be easily respected : when SAS signals are on different carriers than OAS/ CAS1 signals, it will be possible to deny the access to OAS/ CAS1 users without denying the access to SAS users (who are in this case known and controlled). From a safety point of view, encrypted signals are better protected against spoofing. From a liability point of view, as the SAS service is assumed to be guaranteed, the liability of the service provider will be enlarged and encryption will provide better means for controlling SAS users. From a legal point of view, there is no formal opposition with Chicago Convention and Wassenaar Agreement.
The SAS services shall be free of direct charge for users and the encryption is not a means for payment of SAS services.

The implementation of encryption shall be optimised in order to limit at maximum the key management constraints and ease the SAS user terminal maintainability.
One key question is related to the choice of the encryption algorithm : a secret level algorithm offers a higher robustness whereas a public level algorithm (only the keys are secret) will be more easily accepted by the SAS community.

In term of services, as for CAS1, the SAS can be delivered either Globally (**SAS-G**) based on a global integrity network with a Time to Alarm requirement of 6s to 15s, or Locally (**SAS-L**) with a time to alarm of 1s, the local differential correction being broadcast from local component via UHF-VHF links.
Galileo intends to provide a world-wide guaranteed service. However, for liability issues, it is proposed within Galileo architecture to offer a capacity for some regional services with the same level of performances through channels where the region authorities provide a status on Galileo performance to their users.
Regional services (outside Europe) can be provided through the implementation of regional components, based on integrity monitoring and control ground segments. The resulting integrity messages are sent to Galileo global component for broadcast within a reserved slot in the Galileo signal in space. The regional service is then an overlay to the Global service, the regional messages being under the responsibility of each region. This regional service broadcast through Galileo MEO satellites only and is called **SAS-RM** (for Regional by MEO satellites). An option is also considered where regional messages are broadcast by GNSS1 GEO satellites :this service is called **SAS-RG** (for Regional by GEO satellites).
In order to improve the availability or the robustness and reliability, a large part of SAS users will probably take benefit of a combination of SAS-G or SAS-RM signals with GPS L1 and L5 SPS signals. In this case, **SAS-GS** and **SAS-RS** services will provide integrity for both Galileo and GPS signals.
Other services for European SAS users are provided by the evolution of EGNOS system as described in Section 4.6.
As for OAS-CAS1, the SAS users will combine SAS signals with information from other sensors or systems.

2.4.4 Governmental Access Service (GAS)

Galileo is a civil system providing a robust service called GAS for Governmental Applications. This service will be used by several categories of users including military and other governmental communities (police, fire, ambulances, transport of nuclear waste, military, etc.). The control of this service will be ensured by civil bodies.
The GAS service is aimed to be an operational navigation service even in periods of war or crisis (terrorism for example) when other services may be jammed on a voluntary basis or not.

The GAS service shall therefore be separated from other services or it shall be possible to deny other services without impacting GAS services. The GAS service shall be free of direct charge and limited to governmental users.

The identified governmental applications are requiring about the same level of availability, accuracy, integrity and continuity performances as SAS in Global, Local or combined with GPS SPS signals. Therefore three GAS services are foreseen : **GAS-G**, **GAS-L** and **GAS-GS**. It must be noted that for military users, in case of international agreement with the USA, there may be a combination, at user terminal level, of GAS-G signals with GPS PPS signals : this service is called **GAS-GP**.
The main driver for GAS services is the level of signal robustness, in order to be better protected against jamming and spoofing. The control of access by region, user group or user terminal shall follow the security policy.

2.4.5 Timing Services

The Galileo system shall provide a radio-electrical timing service allowing users equipped with a dedicated receiver to get a Galileo Reference Time.

The reference time scale shall be Galileo System Time (GST). The GST shall be synchronised with TAI, at less than 5 ns (1sigma). The time distributed by the system shall be a global co-ordinate time in an inertial system.
The timing services are not separate services but fully included within the four former navigation ones.
For a large part of users such as scientists, OAS signals will be sufficient and the only potential market will be for specialist time receiver manufacturers.
However, few applications are requiring a better timing accuracy or a certain level of integrity (in competition with RAIM techniques) and may use CAS1, SAS or GAS services depending on the applications.

The critical requirements for timing services deal with the timing accuracy (variation between services) and the frequency reference accuracy (required to be better than 10^{-11}). It shall be noted that the timing accuracy requirement is more severe for static users, as noted in the table overleaf.

2.4.6 Service Performances

The requirements for each service to be provided are summarised in Table 2.4.6-a. They also include services to be provided by a conjunction of Galileo and GPS with GNSS1 augmentations, i.e taking into account the EGNOS services, assuming that EGNOS is integrated in Galileo.

These requirements are given as performances at user level including the contribution of user receivers.

For SAS-G services, different services are described in order to be in line with Civil Aviation standardisation approach. They correspond to different configurations of the system (RAIM with GIC or not, etc.) and impact differently the design of the system. The SAS-G en route and NPA continuity requirements are drivers for the required reliability of the system, whereas the SAS-G and SAS-R CAT-1services drive the integrity architecture.

Service Level	Other System	Number of Frequencies	Coverage (lat)	Masking Angle (°)	Accuracy				Continuity risk	Integrity				Availability
					Position (NSE 95%)		Velocity	Timing		Risk	TTA	Hor. Alarm Limit	Vert. Alarm Limit	
					Hor.	Vert.								
OAS-G1	No	1	90S/90N	10	16m	36m (30m up to 75°)	50 cm/s	0.1s		NA	NA	NA	NA	99%
OAS-G2	No	2	90S/90N	10	7m	15m (12m up to 75°)	20 cm/s	0.1s		NA	NA	NA	NA	99%
OAS-GS	GPS	2+2	90S/90N	10	4m	10m (8m up to 75°)	20 cm/s	0.1s		NA	NA	NA	NA	99%
CAS1-G	No	2	90S/90N	10	7m	15m (12m up to 75°)	20cm/s	10 to 20 ns static 100ns dynamic	2.10^{-4}/ hour 5s outage	2.10^{-7}/ hour	10s	20m	45m (35m up to 75°)	99%
CAS1-GS	GPS	2+2	90S/90N	10	4m	10m (8m up to 75°)	NA	10 to 20 ns static 100ns dynamic	2.10^{-4}/ hour 5s outage	2.10^{-7}/ hour	10s	13m	32m (25m up to 75°)	99%
CAS1-L1	No	2	local in 90S/90N	10	0.8m	1.2m (1m up to 75°)	NA	10 to 20 ns static 100ns dynamic	2.10^{-4}/ hour 1s outage	2.10^{-7}/ hour	1s	2m	3.5m	99%
CAS1-L2	No	2	local in 90S/90N	10	0.8m	1.2m (1m up to 75°)	NA	10 to 20 ns static 100ns dynamic	2.10^{-4}/ hour 5s outage	2.10^{-7}/ hour	10s tbc	2m	3.5m	99%
CAS1-L3	No	3	local in 90S/90N	10	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd
SAS-G en route	No	2	90S/90N	10	100m	NA	20cm/s	10 to 20 ns static 100ns dynamic	2.10^{-4}/ hour 10s outage	2.10^{-4}/ hour	15s	556m	NA	99%
SAS-G NPA	No	2	90S/90N	10	100m	NA	20cm/s	10 to 20 ns static 100ns dynamic	2.10^{-5}/ hour 5s outage	2.10^{-7}/ hour	10s	556m	NA	99.9%
SAS-G CAT1	No	2	90S/90N	10	6m	7.7m	20cm/s	10 to 20 ns static 100ns dynamic	10^{-5}/ 15s 1s outage	3.510^{-7}/ 150s	6s	11m	20m	99.9%
SAS-GS CAT1	GPS	2+2	90S/90N	10	3m	4m	20cm/s	10 to 20 ns static 100ns dynamic	10^{-5}/ 15s 1s outage	3.510^{-7}/ 150s	6s	8m	10m	99.9%
SAS-R CAT1	No	2	local in 90S/90N	10	6m	7.7m	20cm/s	10 to 20 ns static 100ns dynamic	10^{-5}/ 15s 1s outage	3.510^{-7}/ 150s	6s	11m	20m	99.9%
SAS-RM	GPS+ GNSS1	2+2	Regional – GNSS1	10	3m	4m	20cm/s	10 to 20 ns static 100ns dynamic	10^{-5}/ 15s 1s outage	3.510^{-7}/ 150s	6s	8m	10m	99.9%
SAS-L	No	2	local in 90S/90N	10	1m	1.5m	20cm/s	10 to 20 ns static 100ns dynamic	$5*10^{-6}$/ 15s 1s outage	$2*10^{-9}$/ 150s	1s	3m	5.5m	99.9%
GAS-G	No	2	90S/90N	10	6m	7.7m	20cm/s	10 to 20 ns static 100ns dynamic	10^{-5}/ 15s 1s outage	3.510^{-7}/ 150s	6s	11m	20m	99.9%
GAS-GS	GPS	2+2	90S/90N	10	3m	4m	20cm/s	10 to 20 ns static 100ns dynamic	10^{-5}/ 15s 1s outage	3.510^{-7}/ 150s	6s	8m	10m	99.9%
GAS-L	No	2	local in 90S/90N	10	1m	1.5m	20cm/s	10 to 20 ns static 100ns dynamic	$5*10^{-6}$/ 15s 1s outage	$2*10^{-9}$/ 150s	1s	3m	5.5m	99.9%
EGNOS-2	GPS+ GNSS1	1	Regional GNSS1	5°	100m	-	-	20 ns	2.10^{-5}/ hour	$2*10^{-7}$/ hour	10s	556m	-	99.9%
EGNOS-3A	GPS+ GNSS1	1	Europe	5°	7.7m	7.7m	-	20 ns	10^{-6}/ 150s	$3.5*10^{-7}$/ 150s	6s	20m	20m	95%
EGNOS-3B	GPS+ GLO+ GNSS1	1	Europe	5°	4m	4m	-	20ns	10^{-6}/ 150s	$3.5*10^{-7}$/ 150s	6s	10m	10m	95%
EGNOS-3C	GPS+ GNSS1	2	Regional GNSS1	5°	7.7m	7.7m	-	20ns	10^{-6}/ 150s	$3.5*10^{-7}$/ 150s	6s	20m	20m	99%

Tableau 2.4.6-a: Galileo service requirements

2.5 SAR SERVICE

The Search and Rescue (SAR) mission considered on Galileo has a forward link from the user to the Mission Control Centre (MCC) and a feedback link from the Rescue Control Centre (RCC) to the user. Such a feedback link is not provided by the COSPAS-SARSAT system.

The SAR mission on Galileo will offer the following basic performance requirements.
First, it will ensure the compatibility with COSPAS-SARSAT beacons. The SAR payload will detect 406-406.1 MHz beacons with at least the same precision as COSPAS-SARSAT and maintain a non-Automatic Dependence Surveillance location mechanism for legacy compatibility and potentially for the recovery of weak/jammed signals.
Second, it will improve detection and location performance in reducing significantly the detection/location delay (no more than 10 minutes) in maintaining the current COSPAS-SARSAT location accuracy.

This proposed SAR mission will :

- reduce the confirmation delay which is currently up to several hours between two LEO satellites,
- maintain a high probability of distress signal detection (better than 98%),
- cope with a 10-fold increase of the user population size (3 million).

Although there are a number of SAR-dedicated communication links, implementing a feedback data-link relayed by Galileo MEO satellites would have a number of operational advantages: in addition to the global and highly redundant coverage of the whole Earth, there is a possibility to easily integrate in basic distress beacons some two way protocols together with a limited information display.

Among the new services made feasible by a feedback link are:

- the acknowledgement from the Mission Control Centre (MCC) to the user in distress (this could trigger the flashing of a small lamp on the beacon) as soon as the distress signal is detected. Such a service could help to reduce the false alert rate,
- the remote triggering of a beacon so as to try to locate someone reported missing or presumed in trouble (e.g. following an alarm raised by worried relatives or an abruptly interrupted radio communication),
- the faster transmission of more accurate distress signals,
- the broadcasting of messages to alert other users in the vicinity of a distress situation, so as to require them to contact the SAR authorities and co-ordinate distant SAR intervention (reducing SAR operational delays).

Moreover the provision of beacon signalling enhancements, such as the additional user infraction (craft name and type, number of people onboard, onboard communication equipment), will enable to optimise SAR resource allocation.

The considered frequency plan is the following :

- forward link : assignment, in the 1544-1545 MHz, of a channel at either end of the band, which has the advantage of being already a SAR assignment (beacon to satellite).
- feedback down-link (new service) : assignment of a slot in the navigation message (satellite to beacon).

2.6 COMMUNICATIONS SERVICE

One of the main results of the user needs analysis is that most applications require only low data rates and that an alternate operation of the navigation and communication functionality of the equipment is allowed, except for applications where correction data are required and, of course, within traffic management systems where map data have to be downloaded to the vehicles.

Terrestrial and satellite communications systems that can meet the needs of the user service requirements are summarised hereafter :

- Existing and Forthcoming terrestrial communication systems:
    - DECT (radio access technology),
    - GSM900/DCS 1800 (GSM 1900) (digital cellular standard),
    - HSCSD (first evolution of the GSM cellular standard),
    - GPRS and EDGE (Further evolution of the GSM cellular standard),
    - cdmaOne (IS-95) (first generation of Narrow band CDMA (IS-95),
    - UMTS–3G-IMT 2000-cdma 2000,
    - WAP,
    - …
- Existing and Forthcoming GEO only satellite communication systems:
    -
    - INMARSAT standard-A, standard-B, standard-M,
    - INMARSAT Phone mini-M
    - INMARSAT standard-C, C3
    - INMARSAT standard-D, D+
    - INMARSAT standard-E
    - INMARSAT Aero-C, -L, -I, -H
    - EUTELTRACS, OmniTRACS
    - Emsat,
    - ESA PRODAT (EMSS),
    - …
- Existing and Forthcoming Non-GEO only satellite communication systems:
    - ORBCOMM
    - LEO-ONE
    -
    - GLOBALSTAR
    - ICO
    - …

Several solutions for providing communications services related to navigation have been considered : dedicated payload on-board Galileo satellites, combination with existing/ forthcoming terrestrial and satellite systems. The analyses were based on following criteria : Cost-Benefits Analysis, political/ international/ legal issues, regulatory issue, and programme risk.

The baseline recommended for Galileo is to combine existing or forthcoming communication terminals with the Galileo receiver.

3 SYSTEM CONCEPTS

3.1 CONSTELLATION ANALYSIS

3.1.1 Introduction

The aim of this section is to provide a summary of the elements used for performing the trade-off between a MEO-only and a MEO+GEO constellation for Galileo system.
The same assumptions have been considered to determine the size of each constellation and the associated system cost.
These assumptions consisted of the following set of parameters :

- Performance requirements – horizontal and vertical accuracy, integrity, continuity and availability,
- Error budget for the satellite SIS,
- Performance with different masking angles,
- Coverage.

3.1.2 Constellation sizing

Taking into account these assumptions, the analyses have identified the optimised size for the two types of constellation. They considered satellites incorporating full Navigation payloads, using atomic clocks, with satellites configured for a global coverage. Three configurations have been identified:

- 30 MEO for a world-wide coverage,
- 24 MEO + 8 GEO for a world-wide coverage,
- 24 MEO + 3 GEO for a European coverage.

3.1.3 Outcomes of the analyses

3.1.3.1 Cost

The cost of the 30 MEO constellation is some fifteen percent lower than a constellation of 24 MEO with 3 GEO. These figures are based on an output from the ESA Comparative System Study (1999), and must therefore be taken as preliminary, whereas GalileoSat study (2000) states that the 30 MEO constellation is some fifteen percent lower than a constellation of 24 MEO with 8 GEO.

3.1.3.2 Performance characteristics

On a global basis, with a 10 degree masking angle, both constellations achieve an horizontal (2 dimensional) accuracy better than 10 meters. However the 30 MEO constellation shows a more uniform accuracy on a global basis and is not subject to slight performance degradation in the mid-latitude regions like the MEO+GEO case.
On a global basis, with a 10 degree masking angle, both constellations achieve a vertical accuracy better than 12 meters. The 30 MEO constellation shows a more uniform accuracy on a global basis. However, the 24 MEO plus 8 GEO constellation achieves a better vertical accuracy than 30 MEO case, in some specific areas.

3.1.3.3 Sensitivity to masking angles

The better performance, particularly in the northern countries latitudes, is achieved by the 30 MEO constellation for both horizontal and vertical accuracies when used in an urban environment (25 degree masking angle).

In difficult environments like urban canyons, the GEO fixed position with respect to the earth leads also to permanent masks in a given area, whereas the moving MEO satellites allow more easily to obtain a position measurement from time to time.

The performance of the 30 MEO constellation is significantly better when comparing accuracy availability in Northern latitudes in the event of satellite outages. A high availability (>95%) is maintained to approximately up to 78 degrees latitude with the 30 MEO constellation with one satellite outage and almost as good for the two satellites outage condition. On the other hand, the 24 MEO plus 8 GEO constellation demonstrates a fall-off in availability (<90%) at mid latitudes (54 degrees) with no satellite outage and below 75% availability with two satellites out.

3.1.3.4 Programme risks

The presence of GEO satellites in the constellation undoubtedly adds several risks to the programme:

- Development risks, which are largely increased due to the development of two types of satellites instead of one, concerning for instance direct material, but also maintenance and manufacturing chains (platform, antenna), as well as two types of ground control segments (antennas),
- Operational and LEOP risks, since GEO operations and LEOP are very much different for GEO compared to the MEO case,
- Technical risks, associated for example to the difficulty to perform accurate orbit determination and synchronisation of GEO. These functions are much more complex than for MEO, which have a more predictable orbit,
- Potential risks to actually get the necessary GEO orbital slots : not considered yet,
- Necessity to foresee two types of launchers firstly for constellation deployment but also for constellation replenishment. This kind of strategy is obviously more complex and less “flexible”.

3.1.3.5 Integration of EGNOS

The presence of dedicated GEO in Galileo constellation could benefit to the integration of EGNOS, if those GEO would also broadcast GNSS1 SIS in addition to Galileo SIS.

Nevertheless, this would lead to a very significant increase of GEO power and weight to accommodate such a feature, which would even be worse if WAAS intends to broadcast GPS L5 frequency in addition to GPS L1 frequency.

In addition, the GEO broadcast implemented in GNSS1 is a current design that needs to be pursued for a sufficient period to ensure a proper transition to GNSS1 “current” users. Nevertheless, this has to be questioned in the long term, knowing that a broadcast of GNSS1 information can be performed through Galileo MEO satellites within Galileo SIS, for future Galileo-GPS “dual mode” receivers.

Galileo GEO would therefore ease the continuation of EGNOS broadcast through GEO, but with a risk associated with the capability to accommodate both Galileo and GNSS1 SIS, and knowing that this is questionable in the long term.

3.1.4 Conclusion

A MEO only constellation is preferable to a MEO + GEO constellation assuming dedicated GEO for ensuring the navigation function, namely providing Galileo Signal In Space.

Payloads embarked on GEO satellites are anyhow considered for performing following functions:

- EGNOS transponders, to ensure the continuity of service for current EGNOS users,
- internal communications for Galileo system.

3.2 GALILEO GLOBAL INTEGRITY CONCEPT

The concept proposed for the provision of Galileo integrity information shows a significant advantage over GPS. Together with the navigation service, provided de facto world-wide with a MEO constellation, an integrity information will be provided on the same geographical coverage. Compared to current SBAS systems, based on GEO satellites, the service will cover the poles and all landmasses (e.g. Africa, South America, islands everywhere).

In addition to the integrity information about its own satellites, Galileo will provide the same kind of information about the GPS satellites, allowing dual-mode Galileo+GPS receivers to get, through the SIS of the Galileo satellites, an integrity information on all the satellites they use within a world-wide coverage.

This service is provided to the users through the following data :

- Signal In Space Accuracy (SISA),
- Integrity flags.

3.2.1 SISA

The uncertainty estimates of the Galileo (or GPS pseudo) ranges transmitted by Galileo are called Signal In Space Accuracy (SISA). For a given Galileo or GPS satellite, the SISA (4-bit parameter) will account for uncertainties in the clock and ephemeris residuals, associated to a given Satellite Navigation Frame (SNF index). For the purpose of the Global Service, SISA computation will be centralised, based on measurements collected by the network of monitoring stations. SISAs will be determined by the ground segment (clock and orbit determination module) once an hour approximately, at the same time as the clock and ephemeris parameters. It is currently assumed that the dynamic behaviour of clock and ephemeris errors are sufficiently slow to justify such a low update rate.

In order to minimise the Time To First Fix (TTFF) performance while limiting the necessary throughput (total system bandwidth is very limited), it is proposed that SISAs are broadcast to users every 30 seconds (TBC) through the Signal In Space. The SISA related to a Galileo satellite is broadcast in its own SIS only. The SISAs related to GPS satellites are broadcast in the SIS of some Galileo satellites.

3.2.2 Integrity flags

Using the approach described above, users will have access to an estimate of their position error in a fault-free environment. However, for demanding operations, it is necessary that users are warned of a failure within a very short time delay (e.g. for civil aviation : 10 s for Non Precision Approaches and 6s for Cat I Precision Approaches). This requirement is not compatible with the once an hour rate chosen for computation of SISAs. It is therefore necessary to implement a specific processing in the ground segment able to monitor continuously the signals transmitted and send real time alerts to users in case of any doubt on the signal quality, including validity of the SISA value already broadcast.

For a given satellite, the Integrity Flag (IF) is a 2-bit parameter that can be coded as follows :

- SISA is OK : USE this satellite,
- satellite is not monitored,
- SISA is not OK : DO NOT USE this satellite,
- spare (use of the fourth value of the 2-bit parameter not defined).

3.2.2.1 Integrity tables

Due to bandwidth limitation, the complete integrity table, containing integrity flags and associated SNF for all satellites of a given constellation, will be broadcast only every 30s approximately. Each Integrity Table is identified by a Global Integrity Context Index (refreshed each second in the navigation message) that changes when the table is modified.

Regarding the access between the ground segment and satellites, only some Galileo satellites are continuously accessed from the ground in order to receive these tables and broadcast them in their SIS. This selection is driven by the requirement to have at least 2 satellites broadcasting integrity tables, above 25° of elevation, for any user located world-wide.

3.2.2.2 Immediate integrity alarms

In cases of problem or failure, the users must be informed as soon as possible. These cases are the following ones :

- a satellite was OK and is no longer OK,
- a satellite was OK and is no longer monitored.

Then, an immediate alarm is sent to the users through the Galileo SIS, without waiting for the next broadcast of the complete table.

If too many alarms are raised at the same time by the ground segment, the SIS capacity will not allow to broadcast all of them at the same time. This risk is monitored by the systematic broadcast of the Global Integrity Context Index in the SIS each second. The users are immediately advised of the number of alarms raised, even if they do not receive all of them at once. In this case, they stop using the constellation until the receipt of all the alarms or until the next receipt of the complete integrity table.

This index also allows users having lost the signals during a short period of time to know if the integrity status changed during this period or not and be able to use the system without waiting for the next issue of the complete integrity table (if no alarm occurred as reported in the Integrity Context Index).

3.2.3 Regional overlay integrity concept

The proposed scheme provides integrity at global level. All integrity data for both Galileo and GPS are transmitted through the MEO satellites as part of the navigation message.

For Europe, there is no specific regional service required since the global integrity information discussed above can be used, Galileo being under European control.

For institutional reasons, regions outside Europe may want to have a way to provide their own integrity information to users, independent from the global service. The technical baseline under investigation allows this scenario for a number (TBD – around 8) of different regions. In this case, the regional service will be provided by the infrastructure developed for global service plus a regional infrastructure under the responsibility of the region. This gives to the region a way to cross check and override if necessary the information sent by the global integrity component.

For the systematic broadcasts, the regional integrity scheme is identical to the global scheme : each region can independently send a complete Integrity Table every 30 seconds and a Regional Integrity Context Index each second.

For the immediate alarm broadcast, the scheme is a little different in order to optimise the use of the available bandwidth by using a kind of overlay concept :

- specific regional alarms would be broadcast through the SIS only if the global service did not already reflect the corresponding alarm,
- on the other way, when an alert is detected and broadcast by the global service, all regional services have to admit it and update their regional index accordingly. Then, if they do not agree on the alarm raised, they will have to wait until the next broadcast of their complete integrity table to advise their users.

In summary, priority is given to the management of the data rate limitation for decreasing the integrity risk, even if the regional services availability is slightly decreased for this purpose.

3.3 SIGNAL DEFINITION

3.3.1 Frequency scenarios

The frequency scenarios have been elaborated in consistency with ITU allocations and are based in particular on the very positive results of the World Radio-Communication Conference that has been held in Istanbul this year.

Nevertheless, alternatives are proposed within the framework of the international co-operations considered with Russia and the United States of America. From the point of view of signal definition, these alternatives could allow wider bandwidth and better performances in the upper part of the L-band, as well as better interoperability with GPS or GLONASS, depending on negotiations between the relevant authorities.

Based on the analysis of the characteristics of the identified navigation services (OAS-CAS1, SAS, GAS), and on the analysis of bandwidths for navigation services, three alternatives have been identified :

- **Alternative 1 :** ***the SAS and GAS services are combined*** using the same encrypted signal but separated by group key management, whereas the OAS-CAS1 services are on different frequencies.
- **Alternative 2 :** ***the OAS-CAS1 and SAS services are combined*** using the same unencrypted signal with only part of the navigation signal encrypted for access to CAS1-SAS users and for discrimination from OAS users, the GAS service relying on encrypted signals on other frequencies.
  A slight deviation to alternative 2 is to encrypt only part of the SAS signals, namely the E5 wide band signals, which offers the advantage of providing selective denial capability with degraded performance without having the need to access to GPS or GLONASS bands. This solution would allow a late decision on encryption, with a potential step back to default alternative 2 if a "no ranging code encryption" is decided.
- **Alternative 3 :** ***the three sets of services are separated***, taking benefit of the use of the large GPS or GLONASS bandwidths, as a result of an international agreement.

3.3.2 Specific drivers

The signal definition has an impact on several performances or constraints which can be antagonistic : measurement accuracy, data transmission capacity, robustness vis-à-vis interference or multipath, receiver complexity, time to first fix, etc.

Due to the existence of contradictory requirements, it is not possible to optimise all performances together; this is the reason the following strategy was adopted :

- satisfy all requirements in nominal conditions,
- favour **robustness** by optimising sensitivity margins, in order to guaranty a minimum level of performances, even under very difficult environment conditions.

The consequences of this approach on signal definition are :

- very strong limitations of data rates (50 to 150 bit/s for OAS/SAS/GAS),
- efficient coding and error correction capability (Viterbi decoding),
- capability to process acquisition, tracking and receive data on several carriers for each service,
- diversity techniques (e.g. same integrity data on several satellites),
- modulation including signal components without data (pilot channel) to enable tracking at very low signal to noise ratio (20 to 30 dBHz range),
- received power at the user level 5 dB higher than current GPS specifications (but equivalent to the objective of the future GPS).

3.3.3 SIS Compatibility and band selection

In the course of **WRC2000** preparatory activities, an early recommendation for an OAS spill over into both GPS L1 and GLONASS, mapping of GAS to C-band and identifying potential interference problems in E6 (due to high-power military air-surveillance and wind profiler radar) was made. Following the positive outcome of the conference, the work focussed on deriving a methodology for **intra- and intersystem RNSS compatibility analyses**.

The major results from these analyses are:

- Among the options studied, direct overlay of Galileo OAS with GPS C/A code in L1 is the worst case with regards to mutual interference (this could be reduced by offsetting the OAS carrier frequency or increasing the chip rate).
- GPS M-Code at nominal power level has no effect on Galileo signal performance in both E1 and E2.
- A direct overlay of Galileo GAS in L1 with GPS M-Code at nominal power levels presents no problems.
- A direct overlay of Galileo OAS + GAS with GLONASS G1 SPS is feasible from an inter-system compatibility point of view.

Taking into account these results and some other considerations, it has been decided to restrict the operational Galileo signals to L-Band, stating on the other hand that C-Band could be considered for an experimental purpose (preparing future applications).

3.3.4 OAS Signal Definition

A thorough **assessment of pulse shaping,** as a function of ranging performance in the presence of multipath, has been performed in order to support a feasibility decision on square root raised cosine [SRC] shaped code chip pulses versus unshaped (rectangular) ones.

Multipath is the most constraining error sources for which square modulation (in a wide bandwidth) presents clear advantages.

Square modulation has been selected as a baseline, although it is more demanding with regards to payload constraints and spectrum regulation, The main argument is that this option is more conservative and preserves the possibility to achieve optimal performances.

Another important topic addressed is the **analysis of spreading code properties,** to improve, as far as it is possible, the robustness to intra-system interference. This has been carried out, in particular, by increasing the code length each time it was possible.

Although OAS signals will be used by low cost receiver, for mass market applications, the conclusion has been that the complexity induced by some efficient techniques (as Forward Error Correction or pilot) will be compensated at 2010 horizon by the performance gains.

3.3.5 CAS1 Signal Definition

From the signal point of view, CAS1 is mainly characterised by data transmission requirements. Due to the constraint presented above, it is necessary to dedicate a specific signal to this service with higher data rates.

Navigation message data frame structures have been designed which allow the transfer of urgent integrity data while allowing a flexible format for the transmission of navigation and other data. The use of data rates exceeding that of GPS (50bps) needs **Forward Error Correction** to achieve good performance at practical signal levels. A starting point has been to adopt convolutional coding with soft decision Viterbi decoding in order to balance good performance with acceptable receiver implementation complexity. Interleaving depth is restricted to meet integrity data delay requirements.

The design choices for Galileo so far, while meeting requirements, are still conservative. **Advanced data transmission techniques,** that are closer to modern systems (such as DAB, UMTS) rather than GPS, offer performance benefits not previously achievable. One example is variable rate coding schemes flexibly interpreted at the receiver level, providing a range of features versus cost mapping points applicable to the OAS, CAS1 and SAS classes.

Data message encryption techniques have been studied, in particular regarding the applicability of commercial encryption techniques from other fields (e.g. banking, pay-TV) for the value-added CAS1 data and on the potential benefits of using public key encryption of the integrity message to provide a first-level anti-spoofing capability without requiring the security apparatus and complexity necessary for encryption of the ranging code.

3.3.6 CAS2 Signal Definition

CAS2 definition assumes that there are some civilian users who need service continuity even when normal access to Galileo signals are Selectively Denied (deliberate localised jamming of OAS/CAS1, with encryption of CAS2 ranging code to protect the system from misuse). Therefore CAS2 users correspond to different classes considered by Europe as part of its essential interests - governmental/strategic (identified as GAS) and safety-of-life (identified as SAS). Technical analyses have emphasised three topics in particular:

- The analysis of **TACAN/DME interference** on a civil aircraft receiver in E5 band has led to the adoption of the "**narrow-band/wide-band**" concept, consisting of two signals in quadrature on the same carrier at different chip rates (1.023 Mcps and 10.23 Mcps). This solution avoids re-assigning DME, unlike the current US plans for GPS L5, although there are some impacts on the receiver complexity associated with the concept.
- The analysis of **encryption key management** has focussed on the possibility to broadcast all data necessary to manage different groups of users with a very low data rate.
- Split spectrum modulations have been proposed to spectrally isolate GAS from the other services supported by the same carrier, with the intention to allow selective denial.

3.3.7 Receiver Economical Trade-off

Galileo signal and message specification have been addressed from the perspective of receiver implementation metrics (complexity, recurring cost and performance), considering future digital communication techniques and the four service classes. Main conclusions are:

- There is a range of mitigation techniques for the interference problems identified in the E5 and E6 bands.
- C Band is unattractive for cost-sensitive users but it could be useable for GAS.
- SRC filtering is not preferred for OAS receivers (complexity & cost metrics); receiver impact should be traded against interference to/from GPS bands.
- Code length recommended to be limited for E1 and E2 (for fast acquisition).
- The Time to Alarm requirement reduces the efficiency of interleaving techniques.
- E2 preferred for Low Cost / Mass Market receiver; the signal definition should therefore allow as simple a design as possible.
- There are good arguments for UMTS or GPS interoperability at the receiver level, each of which can drive signal definition.

3.3.8 Conclusion

A complete set of parameters (ICD) has been provided for each signal in each scenario.

Due to the many external parameters and non technical constraints which may have an impact on the signal definition, it is preferred to keep open several options rather than focusing on one specific solution. By doing so, the results obtained in GALA can be considered as the basis for the final definition of the future GALILEO signal.

3.4 TIME MANAGEMENT AND SYNCHRONISATION

3.4.1 Introduction

Time is critical to the success of a Global Space Navigation System. This relates to the synchronisation of the system clocks to a common time as well as aligning the system timescale to international standards such as Atomic Timescale (TAI) and Universal Co-ordinated Time (UTC). Global timescales are usually based on the UTC.

To achieve this timescale, very stable atomic clocks are compared in various locations around the world most major nations. Hence, each nation has its own atomic time (TAI).

These clocks are compared by BIPM, in France, on a monthly basis. A Global TAI is then produced together with the differences from it of all the clocks in the various locations. The weighted average is the Global time and UTC is produced by adding a number of Leap Seconds. This international value of UTC is a calculated Standard. The GPS UTC(USNO) is steered towards the prediction of UTC and achieves a variation of less than 50ns.

Users of GPS can therefore derive a Global time which is very accurate and close to UTC. Galileo System Time (GST) will operate in a similar way and will also steer its timescale towards the prediction of the UTC.

3.4.2 Time management

Galileo will have its own atomic clocks and these will be distributed between Precision Time Facilities, Global Monitoring Stations (GMS). These clocks will need to be synchronised to each other and also to the UTC. The Galileo UTC(k) will have its own title : UTC(GST) for instance. It is the objective to steer the UTC(GST) to be close to UTC and very stable.

Experts in Europe have proposed that National Time Bureau's in Europe contribute to the UTC(GST), which would increase the weighting of the European Clocks in the calculation of UTC. Hence GST should track TAI more closely. To implement this Time Management, the Galileo and European Clocks will be used to produce predictions of UTC. A Galileo Master Clock will be steered to this prediction of UTC and the GMS clocks compared to this Master. The satellite clocks are then compared to the GMS clocks so they in-turn relate to the prediction of the UTC.

The comparison of the clocks with the master will use the two-way transfer technique or the common view technique. The former one is usually preferred as it can be very accurate but it is likely to be more costly.

The use of the National Time Bureau's clocks as part of the Galileo ensemble is attractive but agreements will need to be made, and possibly funding will also be necessary. However, should the external clocks become unavailable then the Galileo Clocks will be capable of continuing in an independent fashion.

3.4.3 Synchronisation

The UTC(GST) is the result of the weighted average of the Galileo and European Atomic Clocks. Data from these atomic clocks is provided to BIPM so that they can provide a calculated Universal Co-ordinated Time on a monthly basis. Currently they are considering methods of improving the update time to about one day but this is still at the study phase. The data is provided to BIPM by comparison methods, between two clocks in two locations, and two main methods are employed. These are :

- Two-way time transfer -which uses a common satellite for comparison of two clocks, in two locations, in both directions such that the errors are common and can be eliminated.
- Common view - which compares the time in two locations with the satellite clock so the difference can be calculated : an average is achieved by taking a series of measurements with the same satellite. This can then be repeated for several satellites to increase the data and accuracy.

4 ARCHITECTURE DEFINITION

4.1 OVERALL ARCHITECTURE DESCRIPTION

The Galileo system is divided into several components which themselves consist of different segments. Each of these segments consists of a set of elements necessary to fulfil the functions of the respective segment. Figure 4.1-1 gives a general overview of the Galileo system, its components and segments and its interactions with the user terminal and external systems and entities.

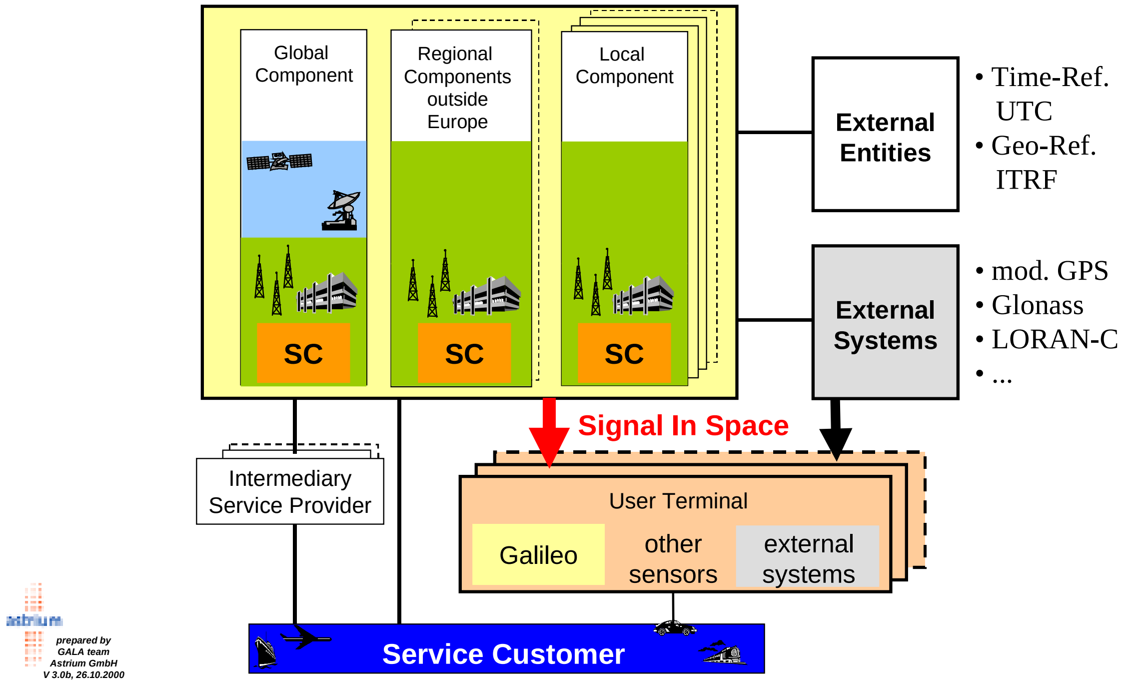


Figure 4.1-1: Overall Galileo architecture – Components

The Galileo system consists of :

- a *global component* with the space segment, the global mission ground segment, a support segment and a management segment, including the integration of the European EGNOS system,
- potentially one or several *regional components outside Europe* with a regional mission ground segment each,
- potentially several *local components* with a local mission ground segment each.

The relation between the system and the service user is provided :

- technically by the signal in space (SIS) which is received by means of the user terminal,
- with respect to subscription, access regulations, billing, and service information directly by the service centres or indirectly via intermediary agents.

Figure 4.1-2 gives a descriptive overview of the Galileo system while Figure 4.1-3 presents a high level overview on the main physical elements and links of the system.

The MEO constellation of Galileo satellites broadcasts the signal-in-space (SIS) to the user terminals where it is processed according to the specifications of the respective service it is used for. Simultaneously, a network of global monitoring stations (GMS) receives the SIS. From the GMS the acquired monitoring data is transmitted to the global navigation control centre (GNCC) for processing, i.e. determination of ephemeris data and clock parameters, global integrity data, and other navigation related information. The processed information is transmitted to a number of uplink stations (ULS) which provide the physical link to the satellites. The ULS are additionally connected to the satellite control centre (SCC) which is responsible for the control of the MEO constellation and for monitoring and control of the individual satellites and their payloads.

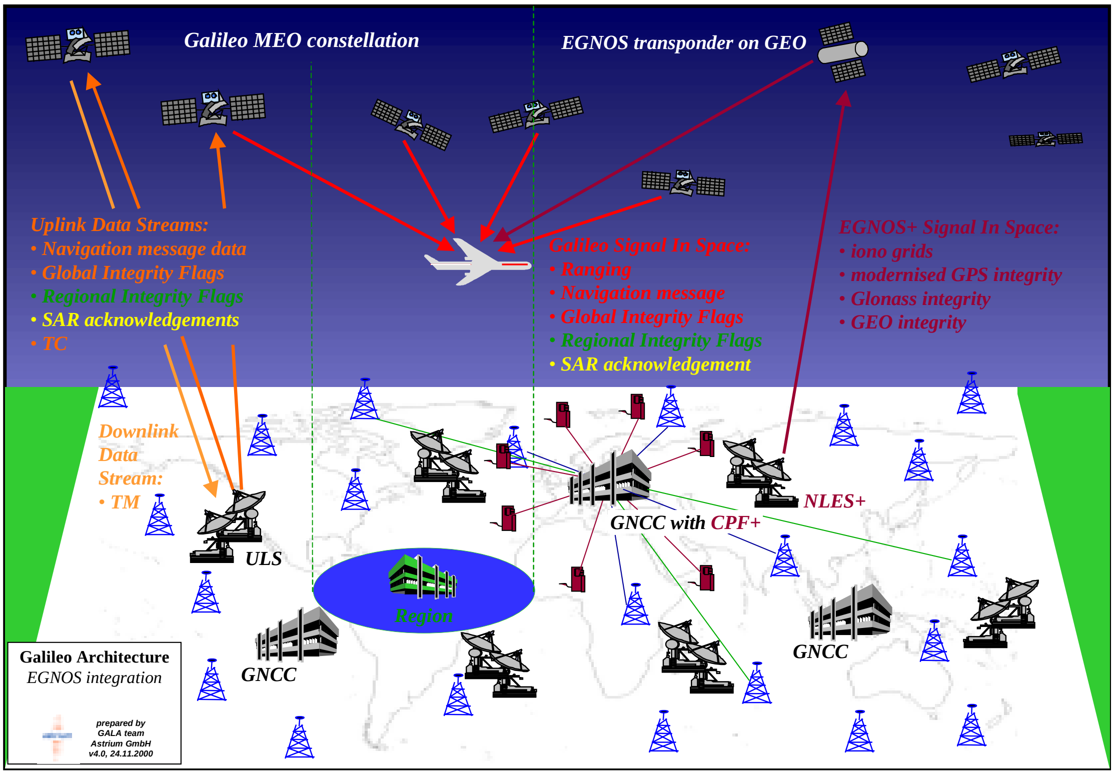


Figure 4.1-2 :Overall Galileo architecture – Descriptive overview

It may happen that, for sovereignty reasons, states or unions of states are not willing to accept the Galileo global integrity to officially allow the use of Galileo within their area.

The proposed regional concept provides them with the possibility to address this issue with Galileo. In this concept, regions on the Earth will be given the possibility to determine their own integrity data which will then be distributed via the Galileo SIS to the users being within the respective regions and using the regional services.

For this purpose, the regions have to establish their own network of monitoring stations and corresponding processing and control facilities. The derived regional integrity information will be transmitted to the satellites via the uplink stations of the global component where it is included into the Galileo SIS.

A special case is Europe, where the EGNOS system is integrated.

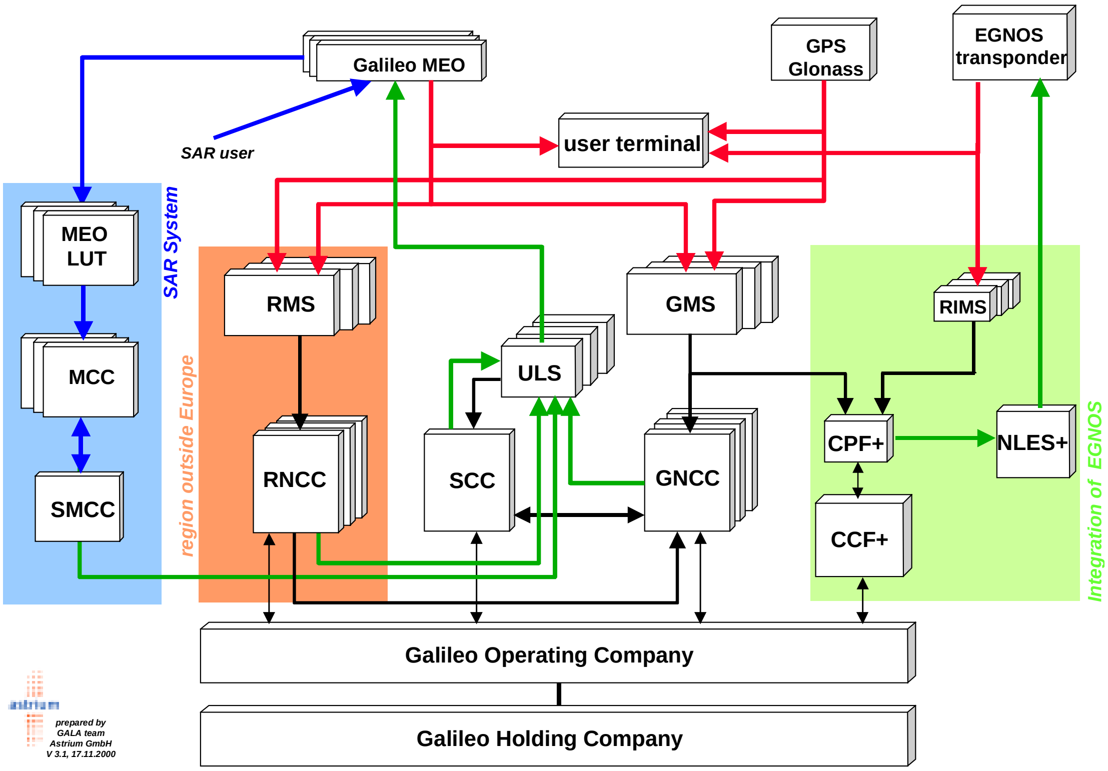


Figure 4.1-3: Overall Galileo architecture – Main physical elements and links

In addition to the navigation and integrity payload the Galileo MEOs also carry a SAR payload which receives distress signals transmitted by users in emergency conditions equipped with a Galileo/SAR receiver or a current SAR system (i.e. COSPAS-SARSAT). These emergency calls are relayed via the SAR transponders onboard the MEOs to the local user terminals (MEO LUT) which transmit the received signal to the associated SAR mission control centres (MCC) for processing.
The MCCs then issue an acknowledgement message that is sent to the SAR Mission control centre (SMCC), which is the single interface of the SAR system with Galileo. From there, the acknowledgement is sent to the ULS where it is included into the navigation message of Galileo and distributed to the respective users via the SIS.

In the following sections the global component, the regional components outside Europe, the local component and the corresponding segments and elements as well as the SAR service and the service provision architecture will be described in more details.

4.2 GLOBAL COMPONENT

Figure 4.2-1 shows the architecture of the global component of Galileo.

From a functional point of view, the global architecture can be divided into the following categories:

- Space Vehicle monitoring, control, and command,
- Provision of navigation and integrity data,
- Provision of SAR services,
- Galileo management and service provision.

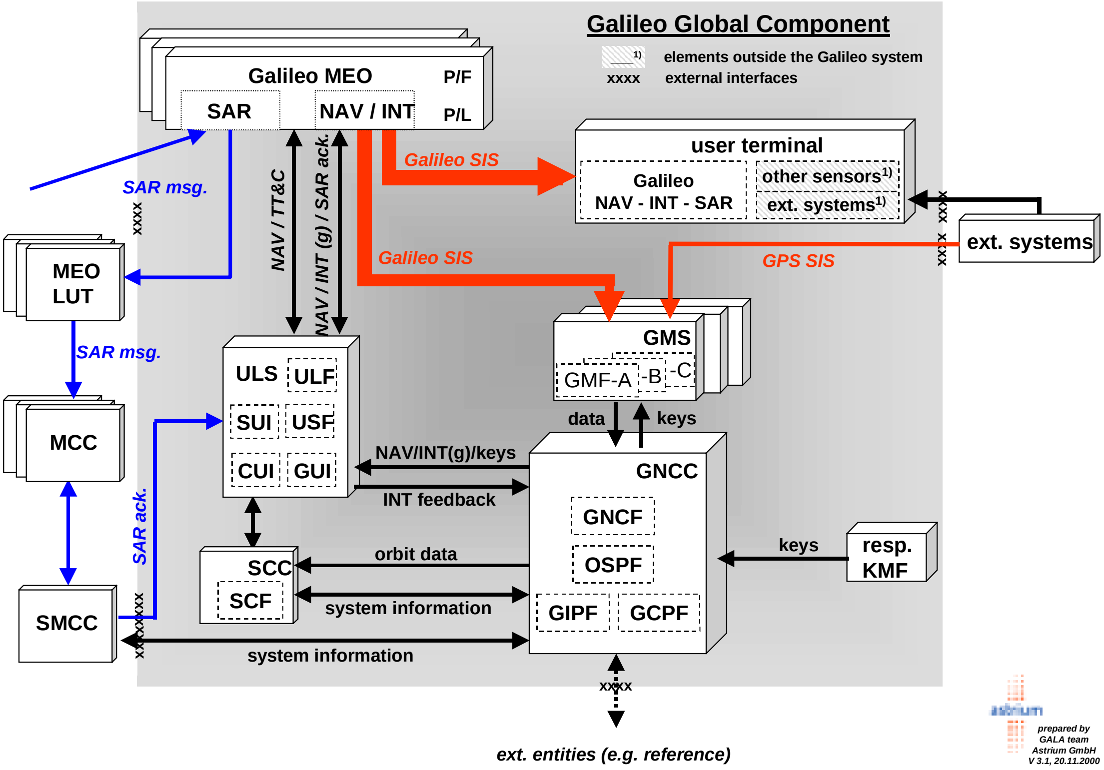


Figure 4.2-1: Overall Galileo architecture – Global component architecture

The Galileo global component consists of :

- the (global) space segment responsible for the space vehicle monitoring, control and command,
- the global mission ground segment responsible for the provision of navigation and integrity data.

4.3 GALILEO REGIONAL COMPONENTS OUTSIDE EUROPE

The main reason for introducing the regional non-European concept for Galileo is the distribution of responsibility and liability for the guaranteed service SAS-R (and the regional – national character of GAS – tbc). For sovereignty reasons, states or unions of states may not be willing to accept the Galileo determined global integrity. This could for instance lead to the case that Galileo is not accepted as navigation means for aviation purposes in the respective area. The proposed regional concept enables these regions to use Galileo together with an integrity information processed under their control and, at the same time, offers them the possibility to distribute this information to their users via the Galileo SIS.

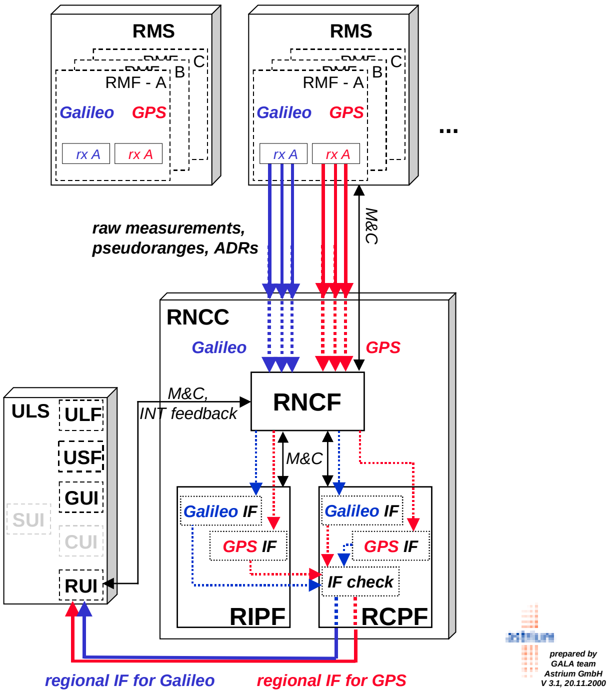


Figure 4.3-1: Galileo regional component architecture for a non-European region

Three different concepts for the implementation of a region outside Europe can be envisaged.

- In case the region decides to be fully independent from Galileo integrity monitoring and processing, it can build its own monitoring network and integrity processing elements. This case is described in Figure 4.3-1.
- In case the region decides to have an integrity processing independent from Galileo one, it can build an integrity processing centre using the monitoring data collected by the Galileo integrity monitoring stations' network.
- In case the region decides to have an integrity monitoring network independent from the Galileo, or considers it not to be dense enough, it can build its own integrity monitoring network or augment the existing global integrity monitoring network with stations for its own needs, respectively.

The proposed architecture for the regional integrity determination reflects the considerations and layout of the global integrity provision's architecture. It is described in Figure 4.3-1. The functionalities of the elements are similar to the functionalities of the respective elements within the global integrity determination chain. For the uplink of the regional integrity data the global Galileo uplink stations will be used into which the data of the various regions is fed via the Regional Uplink Interface.

4.4 GALILEO LOCAL COMPONENTS

Some applications in aviation, marine and rail/road areas have specific requirements that are not met by the global component alone. Generally, these requirements apply in a limited area of coverage. This higher performance can be provided by means of a local component in the very area of coverage.

The technique used to provide higher performance by a local component architecture is known as differential augmentation and the systems behind these techniques are called local Ground Based Augmentation Systems (GBAS).

Local differential augmentation techniques will significantly improve both the accuracy as well as the integrity of the global (and regional) part of the Galileo system. Bases of the differential augmentation are high-quality reference receivers at precisely known locations. Due to the knowledge of its exact location, the reference station estimates the slowly varying error components of each satellite's range measurements and calculates a correction for each satellite in view. The corrections are disseminated to the local component users on dedicated communication (data) links. The corresponding local component user subsystem corrects its pseudorange measurements of each satellite with the received differential correction data to provide more accurate determination of navigation parameters. In addition augmentation can be improved by adding local ground based ranging sources (pseudolites). For security and integrity reasons, integrity monitoring stations supervise the broadcast of differential correction data.

Receivers, adapted to local differential augmentation needs at user level, are able to receive the disseminated corrections and re-calculate the navigation parameters. Therefore user receivers must be adapted to the dedicated local differential augmentation system.

The architecture implementation of a local component is highly application specific. A generic description of a Galileo local component, including the most common elements is anyhow provided in Figure 4.4-1.

The differential Galileo reference station (DGRS) station is accurately surveyed into a known location on the ground. The station's Galileo SIS receiver measures the pseudorange to each satellite in view. Since the ground station's location is precisely known and has received the navigation data from the satellites giving the satellites' position, the pseudorange measurements to each satellite can be corrected against "true" pseudorange. These differential corrections, separately for each satellite, are then broadcast to the user by the integrated data link or via pseudolite transmission.

If only a single DGRS is used for a specific local component implementation, the processing of the differential corrections is performed by the DGRS itself. It is also possible to install a network of DGRS. For these networks, the processing will be performed in a central processing station.

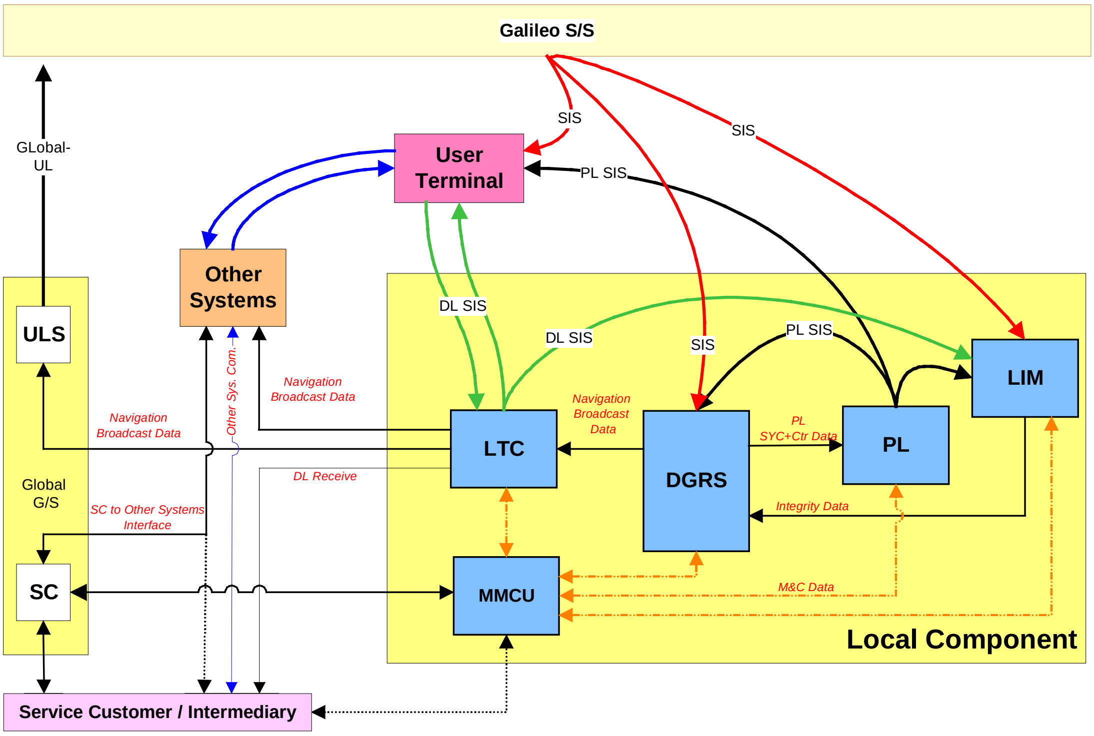


Figure 4.4-1: Proposed Galileo local component architecture

Pseudolites (PL) act as additional pseudo satellites on a local basis. They are ground based transmitters that broadcast a Galileo like SIS signal at Galileo frequency/ies (TBD). A pseudolite acts as an additional ranging source as well as data link for the users. The use of pseudolites provides improvements in accuracy, integrity and availability.

The Local Integrity Monitor (LIM) checks independently the function of the reference station and of the pseudolite stations. The monitoring functions ensure that the reference station broadcasts no hazardous misleading information and no bad signal in space is transmitted by the pseudolite. For the integrity monitor, five main functions are identified, which guarantee the required integrity at each processing level:

- the operation monitor,
- the interference monitor,
- the quality monitor,
- the consistency monitor,
- the broadcast monitor.

The service centre (SC) handles all interactions between the users and the Galileo local component except for the signal in space (LTC and PL) and/or for other means of local data dissemination (differential and integrity data). This includes sales of services, billing, key handling, information on the system’s status, and customer requests.

4.5 USER TERMINAL

The user terminal is the only physical contact between the Galileo user and the Galileo system. Each user has different characteristics and the requirements of the various applications show the diversity of end users and thus, the diversity of user segments to be adapted specifically for each application. In order to clearly address such a wide issue, a step-by-step marketing approach has been implemented.

Based on the outputs of the applications analysis, eight different Core receivers were identified, the main criteria considered being accuracy, cost, integration level, physical constraints, requirement for certification.

Considering this first list of Core Receivers, the most representative applications have been selected, that enabled to address the key issues of the user terminal definition :

- Market : Mass market, Professional market, Safety of Life market,
- Environment : Rural, Urban,
- Carrier : Pedestrian, Aeronautical, Naval, Train,
- Standalone, Integrated,
- Without augmentation, With regional augmentation, With Local Augmentation,
- With or without Hybridisation,
- With or without Communication,
- With or without combination: GPS, UMTS, LORAN C, etc.

The major outcomes of the Baseline Architecture Definition and the Signal Definition activities were then processed to derive six different basic Core Receivers associated to the different Galileo Navigation Services :

- OAS Single frequency for mass market,
- OAS Dual frequencies for mass market or professional market,
- OAS / CAS1 Dual frequencies for professional market,
- SAS for Safety of life market,
- OAS / CAS1 TCAR for professional market (high accuracy applications),
- GAS for governmental applications.

For each Core receiver, an architecture has been proposed. The design for mass market application has been **cost** driven. For all other applications, it has been **performance** driven.

CORE RECEIVER			**AUGMENTATIONS**		
Classes	**Operating Frequency**	**Associated Service**	**REGIONAL**	**LOCAL**	**SENSORS**
OAS single	E2	OAS-G1	N.A.	Yes - TBC	Yes [OAS-G1H]
OAS dual	E2+E6	OAS-G2	N.A.	N.A.	Yes [OAS-G2H]
CAS1 dual	E2+E6	*CAS1-G*	global [CAS1-G]	Differential - *ground* [CAS1-L1] Differential - *SIS* [CAS1-L2]	Yes [TBD]
CAS1 triple	TBD	*CAS1-L3*	N.A.	Phase meas. [CAS1-L3]	N.A
CAS2-SAS	E1+E5	*SAS-G*	global [SAS-G] regional [SAS-R]	Differential [SAS-L]	Yes [TBD]
CAS2-GAS	C-band	TBD	TBD	TBD	TBD

Table 4.5-1 : User terminal design study cases

A detailed analysis has been done for main parts of the receivers :

- RF part – Front End of the core receiver,
- Processing Power,
- PVT (Position Velocity and Timing).

A functional description has been provided for each of them, taking into account the main constraints (SNR, Multipath) as well as an evaluation of the performances achieved (contribution to the range error, availability).

The performances of the complete system are finally assessed at the level of the user segment. Various choices and trade-offs at user segment level enable to address the user requirements in term of UERE, acquisition time, time to alarm, multipath and environmental robustness. These user requirements are globally achievable for the 10 most representative selected applications. Galileo core receivers and user terminals provide at least the same technical performances to the customers as the systems in competition (mainly GPS). See overleaf, as an example, the performance table for the car navigation application.

One can foresee that the competition will also be on price. Decisions on Galileo signal definition having an impact on receiver complexity and cost have therefore to be taken with caution : this is of paramount importance for the mass market segment.

The study has also contributed to identify some potential difficulties (for example: Interference on E5 and E6) which will have to be addressed in next phases of the programme.

Performance Requirements - CAR NAVIGATION				**Receiver performance**		**Assessment**	**Technological potentials / Comments**
				OAS single	**OAS dual**		
Navigation performance	Accuracy	Vertical (m)	40-70	<20	<10	fulfilled	Accuracy improvement allows new functions like additional positioning in the mountainous roads etc.
		Horizontal (m)	25-50	<10	<5	fulfilled	Accuracy improvement allows the simplification of map matching function and as a result a price reduction.
	Integrity	Risk/hr	1e-3	N.A.		-	-
		TTA(s)	30	N.A.		-	-
	TTFF		Medium	Medium		fulfilled	- -
Conditioning factors	Visibility		Partial	Partial		fulfilled	-
	Multipath		Medium	Medium		fulfilled	-
	Interference		Low	Low		fulfilled	-
	Jamming		Low	Low		fulfilled	-
	Dynamics		200km/h-0.2g	N.A.		(fulfilled)	Although information is not available, due to GPS experiment can be excepted to be fulfilled.
Timing	Timing accuracy		Not required	-		-	-
Physical constraints	Power consumption		Low	Low		fulfilled	-
	Size		Medium	Chip-set size		fulfilled	-
	Weight		Low	Chip-set weight		fulfilled	-
	Ruggedisation		Medium	Medium		fulfilled	-
Communication	>>		-	-		-	-
CAS	>>		-	-		-	-
Certification	>>		-	-		-	-
Price	>>		High	<40 Euro		fulfilled	-

4.6 EGNOS INTEGRATION

4.6.1 Introduction

The integration of EGNOS follows an approach which avoids to impact the EGNOS AOC development as currently defined : operational capability in 2004 for a 15 years lifetime.

The necessary evolutions of EGNOS within Galileo are foreseen in one step, and are proposed to accommodate GPS evolutions – provision of the additional civil aviation signal on L5 – that will occur in a time frame similar to Galileo one. The items developed for Galileo to fulfil the new or upgraded GPS services through the Galileo MEO, mainly GMS to collect the future GPS L1/L2/L5 signals, will be also used for the EGNOS services.

The EGNOS GEO payloads will deliver the GPS/GLONASS augmentation. It will be achieved through the GPS L1 frequency and in the future, at a date today estimated around 2012, through the L5 frequency when the GPS has evolved to L5 along with its augmentation standard.

The SIS standard for the GEO channel is the evolved SARPS, taking into account the inclusion of GPS evolution. The capability to broadcast Galileo integrity information through GEO payloads, including the necessary standard evolutions, can be considered if requested by external regions (like the USA).

4.6.2 Integration

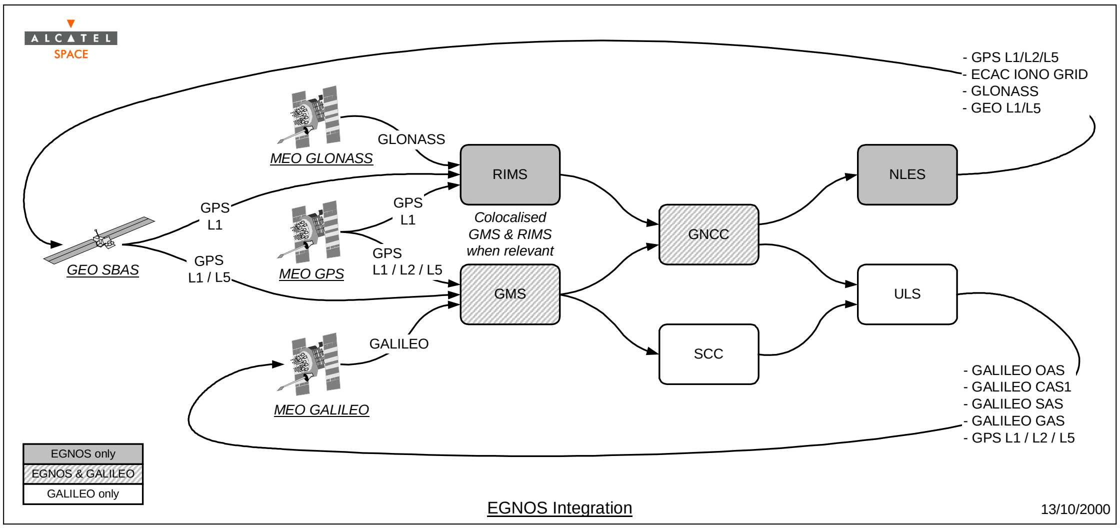


Figure 4.6-1: EGNOS Integration

The raw measurements are acquired in the following sites:

- Upgraded EGNOS RIMS sites: Wherever it is relevant for Galileo services through MEO, upgraded EGNOS RIMS sites collecting data on GPS and Galileo through GMF,
- Other unchanged EGNOS RIMS sites: these concern the EGNOS RIMS sites which have been implemented to only compute the EGNOS ionospheric corrections,
- New GMS sites collecting data on GPS and Galileo through GMF, in areas where there are no RIMS sites able to fulfil the world-wide coverage requested for Galileo services.

The EGNOS functions necessary to achieve the EGNOS services are fully integrated in the Galileo core functions facilities of the GNCC, namely:

- Processing functions:
    - EGNOS GEO orbits,
    - GPS orbit determination which will provide, namely, ephemeris and clock parameters,
    - GPS time reference,
    - GPS SISA, which is an estimation of SIS ranging accuracy to be used by user integrity processing to determine the protection levels,
    - GPS Integrity Flag computation,
    - GPS and GLONASS corrections above ECAC and UDRE,
    - Ionospheric corrections above ECAC.

  The implementation of these processing functions includes an upgrade (HW&SW) of the current EGNOS CPF Processing.
- Independent Check functions:

  These functions are in charge of an independent integrity final check, and its implementation is composed out of an upgrade of the current EGNOS Check Set (for GPS), and a check for Galileo.
- Monitoring and Control:

  The monitoring and control requested to achieve the EGNOS services are:
    - the EGNOS services monitoring and control,
    - the EGNOS items monitoring and control, namely RIMS and NLES,
    - the Galileo Ground Navigation items monitoring and control, namely GMS and GNCC,
    - the monitoring and control of the wide area network connecting the ground items.

The data computed to realise the EGNOS services, are transmitted to the EGNOS GEO through the NLES, according to the upgraded SBAS message format standard. These NLES should be upgraded if the interface with GEO satellites is modified to fulfil the upgraded services, namely provide a second ranging signal on L5.

4.7 COSPAS SARSAT

This section deals with a description of the interface that is foreseen between Galileo and COSPAS-SARSAT, especially for implementing a navigation-coupled feedback link which is the single most specific feature of SAR/Galileo in respect to other SAR systems (INMARSAT-E, COSPAS-SARSAT (C/S), GPRS, etc.).

The COSPAS-SARSAT Mission Control Centres (C/S MCC), will collect and process distress signals from one or more MEOLUTs sites and distribute them to a set of Rescue Control Centre (RCC), on the basis of an institutionally defined repartition of the Earth surface reflecting the organisation of SAR activity and their geographical boundaries. The SAR/Galileo Operational Control Centre receive from the C/S MCC return messages and validate the transmission of the return message to Galileo. Figure 4.7-1 gives an overview of this interface (this proposal has to be validated by COSPAS-SARSAT Organisation).

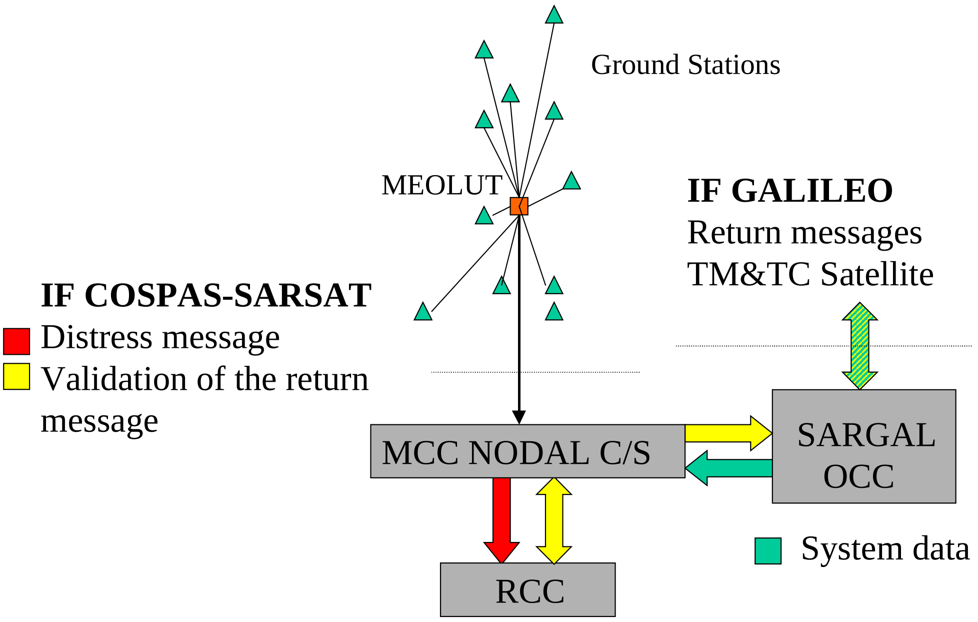


Figure 4.7-1 : Interface with Cospas-Sarsat

4.8 SPECIFIC CONSTRAINTS

4.8.1 Implementation constraints

During the early operation phase of Galileo, the satellite control centre will control a subset of the GMS network and use the data derived from those stations for orbit determination, validation, and the provision of preliminary core navigation services (e.g. OAS). This is meant for allowing Galileo to provide services as soon as possible, even if the full constellation is not yet deployed and the mission ground segment not fully developed. As soon as the mission ground segment is fully installed and validated, the control of the complete set of GMS will be handed over to the global navigation control centre. The GNCC will, from that point, also provide all navigation and integrity related data. The SCC will maintain the capability to control a subset of GMS and provide core navigation services (without integrity information) as a fall-back degraded mode in the case of severe emergencies in the mission ground segment.

4.8.2 Security issues

The Galileo system is intended to take an important role for many users of various kinds (mass market, professional, institutional, governmental). In order to answer to the expectations and to the ambitions that lie on the Galileo system, it must be able to provide a reliable and available service. Thus, it is necessary to counter the various threats that could affect the intrinsic operation of the system, and to avoid the malicious or hostile use of the delivered services.

The security analyses conducted in the frame of the GALA project intend to participate in the specification of the Galileo system and to contribute to its cost estimation. More precisely the threats relative to the Galileo system have been identified and a consolidated list of requirements provided.

Then, the security functions to protect the infrastructure and to protect the exchanged information have been identified to answer to these requirements and threats : authentication, identification and access control function, confidentiality and integrity of internal information, recording and auditing of security relevant events, access control to the services, confidentiality and integrity of the exchanged information, detection and processing of replayed information. Considering the architecture addressed in the previous paragraphs, the security architecture has been proposed and security specifications are also provided to achieve these security functions in the system.

These security specifications identify the flows and the elements of sensitive information to be protected, for each service proposed by Galileo and proposing solutions to realise these specifications.

Several critical issues are addressed in more details, such as the solutions for key management of the various services, the internal communications and the definition of the security modules in each segment of the Galileo system (satellites, user terminals, facilities of the ground segment).

In the frame of the key management analysis, solutions of key distribution have been studied, proposing especially physical supports for the distribution of keys to the users (smart cards, PCMCIA, etc.) and offering a reliable and simplified key management. An Over The Air Rekeying (OTAR) function, depending on the navigation service has also been studied, in order to facilitate the user task and enable to deny remotely a specific user or a group of users.

The key generation and distribution enables to distinguish several groups of users. The possibility to deny one specific user is also considered.

The security analysis has also derived the power levels for the uplink stations and the signal in space power levels, depending on the kind of jammers it is expected to resist to.

This security study shows that the security of the system is a crucial point on which lies the confidence in the system and the usage that can be made of Galileo.

4.9 OTHER SYSTEMS (LORAN-C, GSM/UMTS)

This section addresses the possible evolution of the infrastructure of some other systems (LORANC/ CHAYKA, GSM/UMTS) in case they are used in conjunction with Galileo.

4.9.1 LORAN C/ CHAYKA

4.9.1.1 Evolution of System Concept

The evolution of the existing Loran-C/Eurofix infrastructure could enable the broadcast of differential Galileo correction data within the Eurofix coverage. A regional differential Galileo service could be provided for the European region.

For this evolution, the Loran-C stations must be equipped with a Eurofix modulator (which is expected to be realised by 2008) and each transmission station have to be equipped with additional Galileo reference and monitor receivers.
Following functions would also have to be implemented:

- measurements of Galileo satellite signals,
- calculation of differential correction data,
- transformation of the correction data into a “broadcast format”,
- modulation of the Loran-C signal.

Currently, DGPS and DGLONASS data can be provided by Eurofix. In order to provide additional Galileo corrections, it would be necessary to expand the usable resources available. Therefore either GPS or GLONASS correction data must be removed if Galileo data should be broadcast.

4.9.1.2 Infrastructure Evolution

The following impact on the LORAN C (or CHAYKA) infrastructure has been identified:

- No changes to the Loran-C broadcast **antenna** are necessary.
- No changes to the Loran-C broadcast **transmitter** are necessary.
- The Loran-C **modulators** have not to be modified to broadcast Galileo differential correction data (provided that Galileo correction data can be converted to RTCM format). All NELS stations will be equipped with Eurofix-modulators in 2008.
- The Eurofix stations are currently equipped with one **reference receive**r, but for the final implementation two receivers are planned for each station. Each NELS station should then be equipped with 2 high-end Galileo/GPS/GLONASS receivers to generate the differential correction data.
- The Eurofix stations are currently equipped with one **monitor receive**r, but for the final implementation two receivers are planned for each station. Each NELS station should be equipped with 2 additional high-end Galileo/GPS/GLONASS receivers to monitor the integrity of the broadcast data.
- Software development and update.

4.9.2 GSM /UMTS

4.9.2.1 Evolution of System Concept

There are currently several national geodetic systems, e.g., SAPOS GPPS (Satellite Positioning Service, Geodetic Precise Positioning Service) operated by surveying authorities in Germany, which already use GSM for “near-online” DGPS service.
The data format used is RINEX. The achievable accuracy performance of SAPOS GPPS is 0.01 m (assuming a measurement time of eventually several minutes and a baseline coverage area of less than 17 km).

4.9.2.2 Infrastructure Evolution

If differential corrections are provided, Galileo Reference stations are required. They could be located at the MSC sites. As Galileo receivers would be used for time reference, they could then also provide the corrections.

The reference stations are connected to the GSM (or UMTS) network via a data interface. The provided data is validated by the reference station itself (rather than by GSM/UMTS network components).

A GSM/UMTS user would therefore have the following 3 classes of service :

- UMTS without Galileo, with a possibly sufficient position accuracy for the user (depends on application and user demands).
- GSM/UMTS with Galileo stand-alone : no differential corrections are applied. In this case, only additional hard and software are to be included in the mobile station.
- GSM/UMTS with differential Galileo. In principle, there are two scenarios.
  - The operator builds up his own reference station network. In this case he has on the one hand additional costs but on the other hand he can charge for this service. It is his choice how dense his network shall be and how accurate the corrections can be.
  - The other scenario is that the GSM/UMTS network is used only as a data transmission medium and an external service provider provides the differential corrections (as in the case of RDS). Such a service is already provided with e.g. “SAPOS” in Germany where differential corrections are provided by state authorities (Landesvermessungsamt) via GSM (with typical maximum baselines from 10 to17 km to guarantee the accuracy; not provided in rural areas). In this case the GSM/UMTS network operator has no additional costs (besides of the data traffic which he charges in the usual way).

The mobile station have to be upgraded to use Galileo. This requires an RF front end, a signal processing element to process the position and input and output interfaces for data as well as an MMI interface. The data input interface is needed to obtain Galileo correction data from the GSM/UMTS network (RS-232). The data output interface is needed to display the positioning results if required. Finally, the MMI interface provides the operability by the user. This can be established by e.g. a menu or soft/hard-keys.
It has to be noted that additional hardware and higher processing load result in higher power consumption, which might lead to higher requirements for the power supply.

5 PROGRAMMATICS ASPECTS

5.1 GALILEO IMPLEMENTATION PLAN OVERALL APPROACH

5.1.1 Implementation Plan Logic

The process for the definition of the Galileo Implementation Plan is based on a top-down approach structured in the following main steps:

1. Identification and definition of the Programme Phases. For each phase the objective, the definition, tasks performed, main results and links with other phases have to be defined.
2. Definition of the high level system breakdown into its main components with clear identification of main functions associated to each component.
3. Identification of system architectural scenarios for which to develop the detailed implementation analysis; it is important at this stage to clearly outline the assumptions behind each scenario, as well as the most significant differences between scenarios.
4. Perform the implementation plan analysis for each identified scenario, by detailing for each Programme Phase and for each System Component (as specialised for the scenario under consideration) the planning of the relevant activities, inputs/outputs of each activity, the link between these activities and by identifying which are the main requirements to meet the overall final system configuration in a given time frame, i.e. the FOC of the system.
5. For each scenario, clearly state the main assumptions on which the implementation plan analysis has been based, by providing relevant justifications for these assumptions. Hence perform a risk analysis associated to the present scenario, through the identification of the relevant critical path and possible contingencies.

Moreover, there are some specific issues in the Galileo Programme that need to be considered in the implementation plan analysis: Certification, Security and Replenishment strategy.

5.1.2 Programme Phases

The following main Programme Phases have been considered for the implementation of Galileo:

(a) Definition phase,
(b) Design and Development phase,
(c) System Validation Phase,
(d) System Deployment Phase,
(e) System Replenishment Phase.

5.1.3 Main Assumptions and Justifications

The following high level assumptions have been derived in order to back the proposed implementation concept:

1. The analysis is looking ahead over the period from now to 2028, assuming the launch of full operational GALILEO services in 2008 or 2006.

2. Three options have been considered for the deployment planning :
   - option 1 : FOC in 2008,
   - option 2 : FOC in 2008 with an IOC before 2007,
   - option 3 : FOC in 2006.

3. The following assumptions have been retained as common to all options:
   (a) Regional Component (outside Europe) initial deployment: only considering the European contribution,
   (b) Local Component initial deployment: with reference European system for validation and qualification,
   (c) User Segment has to match with the system validation steps and therefore the user terminals for main categories of applications have to be available well in advance (e.g. one year) the start of operations.

4. As a general recommendation to the implementation plan analysis, particular attention has to be put on the GPS Development Plan from the point of view of ensuring a profitable market for the user segment. Hence, the GPS development schedule (based on the Federal Radionavigation Plan, 1999) has been taken as a reference.

5. Additional assumptions for implementation plan analysis are addressed:
   (a) Site definition for Ground Segment,
   (b) Launchers and Spare Strategies,
   (c) Launch Strategies,
   (d) Satellite FM AIT criteria.

5.2 IMPLEMENTATION PLAN OPTIONS

5.2.1 Galileo Option 1 Configuration

Objective : based on the deployment of 30 MEO satellites constellation such as to achieve the Galileo system FOC on 2008.

The planning is structured on the breakdown of the programme phases and, within each phase, it presents the most important milestones of the major system constituents. The following main considerations apply:

- the plan is essentially conceived for activities at system level, i.e. it does not include development analysis at equipment/subsystem level; to this respect the plan defines requirements for this level of development, in the sense that, at certain times, it is requested that given equipment/subsystems are ready to be integrated at element level;
- it is deemed mandatory, for allowing the validation/certification process to be completed, that all satellites are launched 6 months before FOC;
- considering the available time frame and the activities to be performed during the Design and Validation Phase, the need for an experimental satellite (plus a spare one) on 2003 is identified;
- a PFM launch on beginning of 2005 is foreseen for increasing adequate confidence in the satellite design;
- the launch campaign is carried out from a single site (3 launches per year);
- provision of time for contingencies;
- seventh satellite batch for launch failure risk;
- ground control segment to be ready at 1st quarter of 2005;
- navigation ground segment to be ready at 1st quarter of 2007;
- integrity capabilities could be developed at a later stage;
- the procurement of long lead items is in the critical path.

5.2.2 Galileo Option 2 Configuration

Objective : based on the deployment of 30 MEO satellites constellation such as to achieve the Galileo system FOC on 2008. The phasing is such to have a 24 MEO satellite constellation ready before 2007.

The following main considerations apply:

- the plan is essentially conceived for activities at system level, as for Option 1;
- date of first and last launch are confirmed to be the same as for Option 1;
- in order to achieve a deployment of 24 satellites before 2007 the launch campaign is organised based on a dual pad capability (3 launches per year per pad);
- the satellites of the initial 24 MEO satellites constellation are positioned at the final orbital location;
- the development of three additional satellites to cover launch risk is foreseen;
- the procurement of long lead items is in the critical path.

5.2.3 Galileo Option 3 Configuration

Objective : based on the deployment of 30 MEO satellites constellation such as to achieve the Galileo system FOC on 2006.

The planning is structured on the breakdown of the programme phases and within each phase it presents the most important milestones of the major system constituents.
The planning relevant to Option 3 is extremely critical for the number of activities to be conducted in parallel, which will probably lead to:

- the need for additional production plants;
- take decisions with a poor feedback from precedent phases.

In particular, the following actions are suggested:

- The MEO satellite bus is designed and built for the first experimental satellite (EXP1). The configuration and the bus capabilities in terms of available DC power, mass and size can be frozen at EXP1 launch. Hence it is conceived to initiate, at that time, the production of satellite buses which are marginally affected by the validation campaign results, if any.
- The units of the payload are also built, but not integrated at payload sub-system level in order to be flexible on possible reworks on the basis of the validation campaign.
- Once the validation campaign results are accepted, the payload units are integrated at payload level, the payloads are integrated with the buses for the batch of satellites to be launched together.
- A launch campaign is organised using two launch pads, thus roughly halving the launch campaign duration. This can be done using a single launch complex such as Kourou with a single large team or using the European and the Russian facilities and doubling the teams at launch site.

The following main considerations apply:

- it has to be noted that the plan is essentially conceived for activities at system level, i.e. it does not include development analysis at equipment/subsystems level; to this respect the plan defines requirements for this level of development, in the sense that, at certain times, it is requested that given equipment/subsystem are ready to be integrated at element level;
- it is deemed mandatory for allowing the validation/certification process to be completed that all satellites are launched 6 months before FOC; in this option the last batch launch is reduced to 3 months before FOC;

- in order to achieve a fully deployment on 2006 the launch campaign is organised based on a dual pad (3 launches per year per pad);
- no provision of time for contingencies;
- no PFM launch to increase confidence in the design;
- ground control and navigation segment to be ready mid 2004;
- the procurement of long lead items is dramatically critical.

5.2.4 Risk Analysis Considerations

A risk control oriented approach has been considered identifying the items or events having a potential strong impact on the overall implementation plan and proposing means to mitigate or overcome their effects.

Major Critical Items identified :

- Phase C/D Kick-off ,
- EM breadboard critical items,
- Availability of PFM critical hardware,
- Radiation-hardened highly-reliable parts,
- Ground Segment development,
- Site definition for Ground Segment and agreement with hosts,
- Ground S/W availability,
- Ground Communication Network availability,
- Launchers and Spare Strategies.

Major Contingencies

- Specification not consolidated at beginning of 2001

Mitigation Action: (a) start of the Design and Development phase as planned solely for system elements whose specification are already frozen; (b) parallel activation of a short bridging phase to finalise open points.

- Development Phase delay

Mitigation Action: (a) during the design phase, all critical items shall be clearly identified and the impact of each of them on the development plan has to be assessed; (b) for each critical item a back-up solution shall be identified: in case of high probability of occurrence of a failure in the development or of a large delay, it is recommended to start parallel developments.

- Major non conformance outcome from In-Orbit Validation tests

Mitigation Action: (a) a margin of 6 months is already foreseen in this implementation plan for design revision and modification (beginning of system deployment); (b) areas of possible major problems shall be identified before IOV and investigated as soon as possible during the IOV campaign.

- Launch failure during system deployment

Mitigation Action: (a) include in the FM procurement and manufacturing line (parallel AIT) a spare lot of satellites (in case of no failure, it can be used during the replenishment phase); (b) foresee one additional launch with a contractual clause of rescission in case of no failure.

5.3 CONCLUSIONS AND RECOMMENDATIONS

5.3.1 Conclusions

This chapter summarises the results of the implementation plan trade-off analysis performed on the three main Galileo configuration options. It has to be noted that the identified critical items and major contingencies apply to all three options as well and therefore they need to be properly taken into account, independently from the selected option, by implementing adequate control measures to minimise the impact on the implementation plan. In addition, there are some very important aspects that can be used to discriminate the considered scenarios, to assign a proper level of confidence to each of them, to define a scale of preference to maximise the success of the programme.

5.3.1.1 In-Orbit Validation Effectiveness

The In-Orbit Validation Phase plays a key role in the overall Galileo design and development planning, namely the successful completion of this phase is the preliminary requirement for achieving the schedule of the project. To this respect, it is particularly important to have available an adequate time frame for deploying the reduced (space and ground) system configuration, to carry out the planned validation campaign with suitable margin, to carefully evaluate the major outcomes of this campaign in order to define main feedback actions on the system design. The right completion of this phase definitively gives the go ahead to the system deployment.

5.3.1.2 Successful Deployment Schedule

The Deployment Phase implies the series production of the system elements and the final set up of the complete system. This phase involves problems of integration and testing, both at space and ground levels, different possibilities of launch strategies, in terms of launchers selection and launch campaigns and an integrated process for validating the system step-by-step. The time duration and the degree of complexity associated to this phase give the measurement of the level of risk for not maintaining the schedule.

5.3.1.3 Certification Feasibility

It is assumed that, in order to achieve the FOC, the system needs to be validated and then certified in terms of services provided. It is also assumed that the certification process requires the system validated to be observable for a sufficient time period, during which the required services certification has to be exercised. This observation time period should be at least 6 months.

5.3.1.4 Operational Capability Effectiveness (IOC and FOC)

The best solution for achieving the operational capability of the system is to reach it by an incremental approach, i.e. at least through two main steps such as to allow a suitable development of the integrated process involving the three major issues: the complete deployment of the system, the validation and the final certification. To this purpose, it should be desirable to have the operational capability of the system planned into two main milestones:

- an Initial Operational Capability (IOC), concerning mainly the system already deployed or partially deployed and validated and able to provide all the service range, but with some restriction;
- the Full Operational Capability, when the certification process has been completed and all the services are certified.

In order to quantify the result of comparison among the considered options, a scale based on three levels has been introduced for each of the above parameters. The levels are so defined:

- *low*: means that the complexity of actions and/or the schedule of the implementation plan are such that they make the risk of not meeting the target (NMT risk) to be very high;
- *high*: the complexity of actions and/or the schedule are such that the risk of NMT can be maintained sufficiently low;
- *medium*: means that the NMT risk can be maintained at an acceptable level of confidence.

The following table summarises the trade-off analysis.

	Option 1	**Option 2**	**Option 3**
In-Orbit Validation Effectiveness	medium/high	medium/high	low
Successful of Deployment Schedule	medium/high	medium	low
Certification Feasibility	low/medium	medium/high	low
Operational Capability Effectiveness	low	high	low

5.3.2 Recommendations

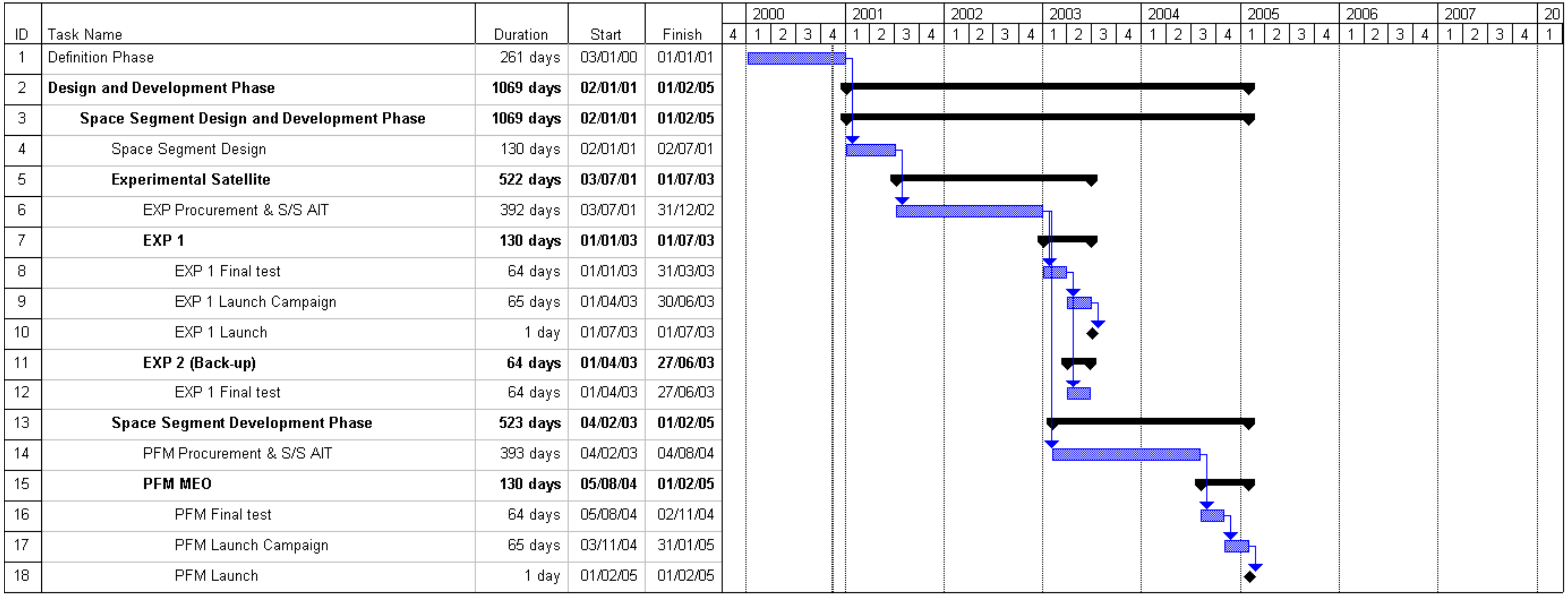
The IOV Phase will include the manufacturing of 2 satellites (EXP1 and its spare EXP2) in the year 2003 and a PFM on 2005. This third satellite may be considered as part of the final constellation.

The main recommendations, for the deployment phase, are:

Rec. 1: The Galileo Option 3 Configuration implementation plan shows a wide range of criticality's. The achievement of system FOC on 2006 by this scenario is very questionable, with the elements available at this stage. Therefore, it is recommended to not consider in the subsequent phase of the Programme this option.

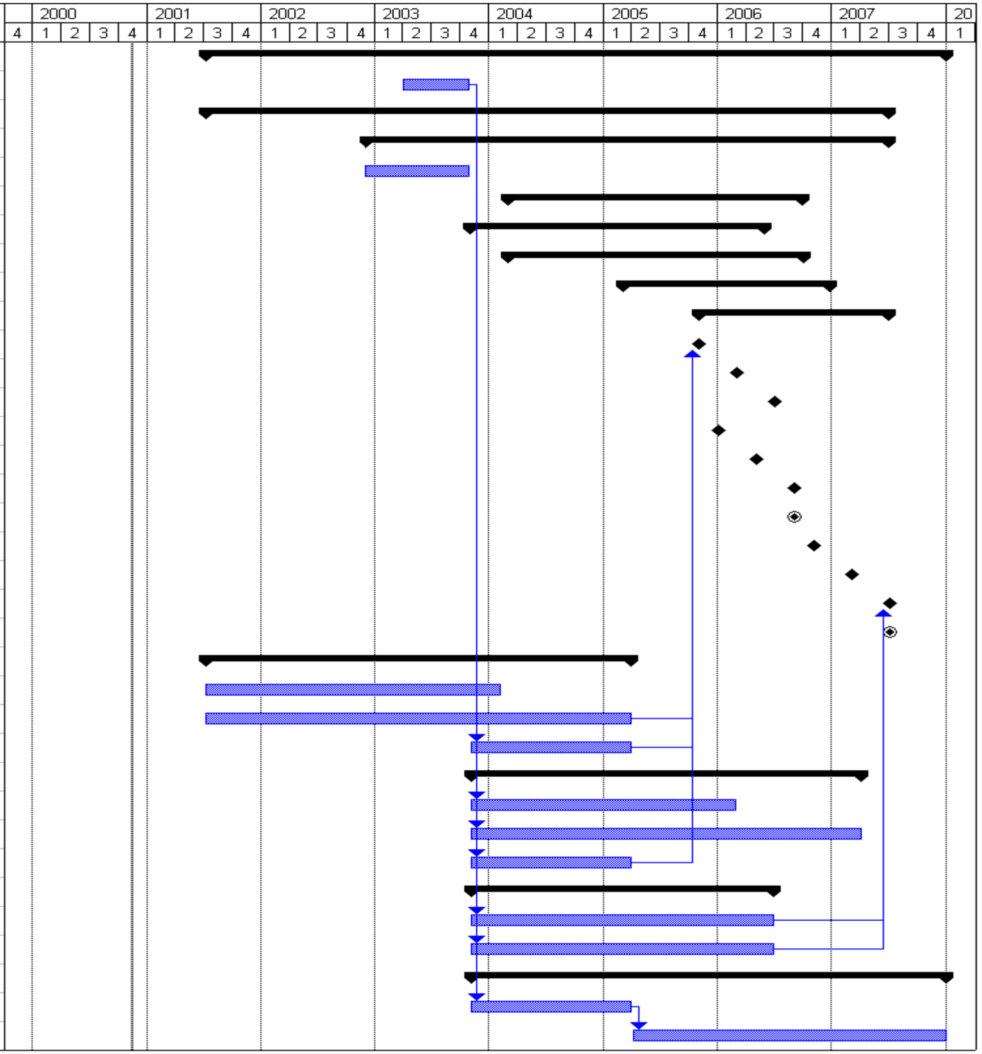
Rec. 2: The Galileo Option 2 Configuration implementation plan shows the same performances as for Option 1 in terms of In-Orbit Validation Effectiveness, but it provides better performances in terms of Certification Feasibility and Operational Capability Effectiveness, that are definitively key issues for the success of the Galileo Programme. The Deployment Schedule in Option 2 results to be more sophisticated than in Option 1, but, in order to reduce the increased risk associated to this approach, this aspect can be optimised by further investigations. Therefore, it is recommended to select the Option 2 as the possible scenario for the Galileo implementation plan.

5.3.3 Development plan synthesis and key milestones (Option 2)

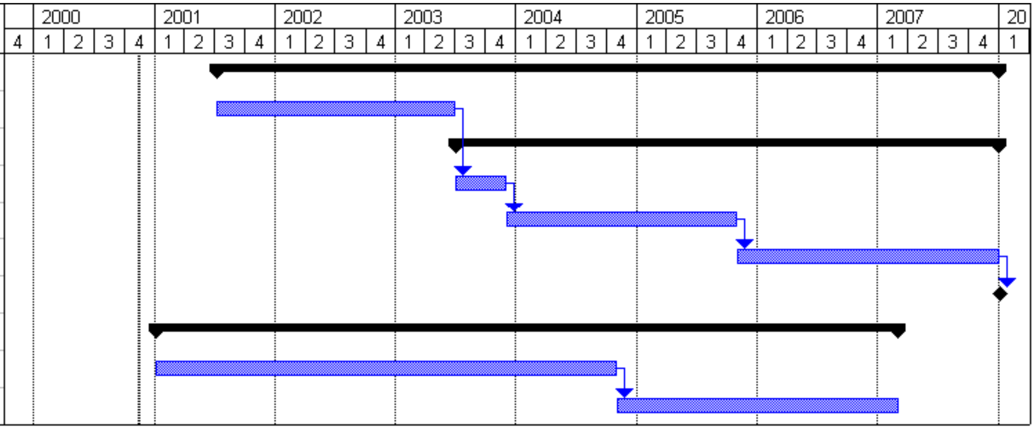


ID	Task Name	Duration	Start	Finish
1	Definition Phase	261 days	03/01/00	01/01/01
2	**Design and Development Phase**	**1069 days**	**02/01/01**	**01/02/05**
3	**Space Segment Design and Development Phase**	**1069 days**	**02/01/01**	**01/02/05**
4	Space Segment Design	130 days	02/01/01	02/07/01
5	**Experimental Satellite**	**522 days**	**03/07/01**	**01/07/03**
6	EXP Procurement & S/S AIT	392 days	03/07/01	31/12/02
7	**EXP 1**	**130 days**	**01/01/03**	**01/07/03**
8	EXP 1 Final test	64 days	01/01/03	31/03/03
9	EXP 1 Launch Campaign	65 days	01/04/03	30/06/03
10	EXP 1 Launch	1 day	01/07/03	01/07/03
11	**EXP 2 (Back-up)**	**64 days**	**01/04/03**	**27/06/03**
12	EXP 1 Final test	64 days	01/04/03	27/06/03
13	**Space Segment Development Phase**	**523 days**	**04/02/03**	**01/02/05**
14	PFM Procurement & S/S AIT	393 days	04/02/03	04/08/04
15	**PFM MEO**	**130 days**	**05/08/04**	**01/02/05**
16	PFM Final test	64 days	05/08/04	02/11/04
17	PFM Launch Campaign	65 days	03/11/04	31/01/05
18	PFM Launch	1 day	01/02/05	01/02/05

ID	Task Name	Duration	Start	Finish
19	**System Deployment Phase**	**1706 days**	**03/07/01**	**01/01/08**
20	Design Revision	154 days	01/04/03	31/10/03
21	**Space Segment Global Component**	**1573 days**	**03/07/01**	**01/07/07**
22	**MEO FM 2-30**	**1204 days**	**01/12/02**	**01/07/07**
23	FM 2-30 Components Procur. Phase (20%)	238 days	01/12/02	28/10/03
24	**FM 2-30 BUS**	**680 days**	**01/03/04**	**28/09/06**
31	**FM 2-30 P/L Units**	**682 days**	**29/10/03**	**01/06/06**
38	**FM 2-30 P/L Integration**	**682 days**	**01/03/04**	**02/10/06**
45	**FM 2-30 Satellite Integration**	**481 days**	**01/03/05**	**27/12/06**
52	**FM 2-30 Launch**	**439 days**	**01/11/05**	**01/07/07**
53	Batch 2-3 launch	1 day	01/11/05	01/11/05
54	Batch 4-6 launch	1 day	01/03/06	01/03/06
55	Batch 7-9 launch	1 day	01/07/06	01/07/06
56	Batch 10-14 launch	1 day	01/01/06	01/01/06
57	Batch 15-19 launch	1 day	01/05/06	01/05/06
58	Batch 20-24 launch	1 day	01/09/06	01/09/06
59	*Readiness of 24 MEO Constellation*	1 day	01/09/06	01/09/06
60	Batch 25-26 launch	1 day	01/11/06	01/11/06
61	Batch 27-28 launch	1 day	01/03/07	01/03/07
62	Batch 29-30 launch	1 day	01/07/07	01/07/07
63	*Readiness of 30 MEO Constellation*	1 day	01/07/07	01/07/07
64	**Ground Control Segment**	**982 days**	**03/07/01**	**01/04/05**
65	Satellite Control Center Develop. (PFM)	679 days	03/07/01	05/02/04
66	Satellite Control Center (Constellation)	982 days	03/07/01	01/04/05
67	TT&C Stations	372 days	03/11/03	01/04/05
68	**Navigation Ground Segment Global Component**	**900 days**	**03/11/03**	**04/04/07**
69	Navigation Control Center	612 days	03/11/03	01/03/06
70	GMF (OSS)	900 days	03/11/03	04/04/07
71	Global Area Network	372 days	03/11/03	01/04/05
72	**Integrity Monitoring System**	**700 days**	**03/11/03**	**30/06/06**
73	GMF (IMS)	700 days	03/11/03	30/06/06
74	ICC	700 days	03/11/03	30/06/06
75	**Local Component**	**1096 days**	**03/11/03**	**01/01/08**
76	Local Component Study	372 days	03/11/03	01/04/05
77	Local Component Test & Verification	724 days	04/04/05	01/01/08



ID	Task Name	Duration	Start	Finish
78	**O/A System Validation Phase**	**1706 days**	**03/07/01**	**01/01/08**
79	O/A System Validation Design Phase	522 days	03/07/01	01/07/03
80	**In-Orbit Validation Phase**	**1184 days**	**02/07/03**	**01/01/08**
81	IOV Campaign Preparation	109 days	02/07/03	01/12/03
82	Initial IOV Campaign	503 days	02/12/03	31/10/05
83	Full IOV Campaign	572 days	01/11/05	01/01/08
84	**Full Operational Capability**	0 days	01/01/08	01/01/08
85	**User Segment**	**1615 days**	**02/01/01**	**01/03/07**
86	Design & Development up to Prototype	1002 days	02/01/01	01/11/04
87	Final Versions	613 days	02/11/04	01/03/07



5.4 BUSINESS AND COST ASPECTS

5.4.1 Business opportunities and marketing strategy

5.4.1.1 Net benefits of Galileo

The analysis of the net benefits of Galileo are summarised in Table 5.4-1.

	2001-2005	2006-2007	2010	2015	2020
	Annual averages				
Supplier benefits (total)	**190**	**930**	**209**	**235**	**268**
User net benefits	**0**	**0**	**1,970**	**4,740**	**7944**
TOTAL economic benefit	**190**	**930**	**2,179**	**4,975**	**8,212**
TOTAL social benefit	**0**	**0**	**245**	**1,015**	**2,075**
TOTAL benefit	**190**	**930**	**2,424**	**5,990**	**10,287**

Table 5.4-1: Consolidation of average annual benefits (million € pa) to Europe

These annual "snapshots" have been converted into a 20-year annual profile. A basic linear interpolation has been applied at this stage. Based on the "most likely" market estimates that were the starting point for this analysis, the total cumulative benefits and costs estimated for Galileo over the 20-year period studied, are as follows:

Total economic benefits:	62 billion €
Total social benefits:	12 billion €
Total benefits:	74 billion €
Total investment costs:	6 billion €[1]

The annual profile of net annual benefits (benefit minus investment costs) are shown in Figure 5.4-1. These become positive from 2008 and increase up to a high estimated level of €10 billion pa by 2020. These net benefit figures give:

- IRR of 75%,
- a positive NPV of 31 billion € (at 5% discount),
- a positive NPV of 15 billion € (at 10% discount).

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[1] This is made up of 3.25 billion € in 2001-2007 and 220 million € pa thereafter (see § 5.4.2).

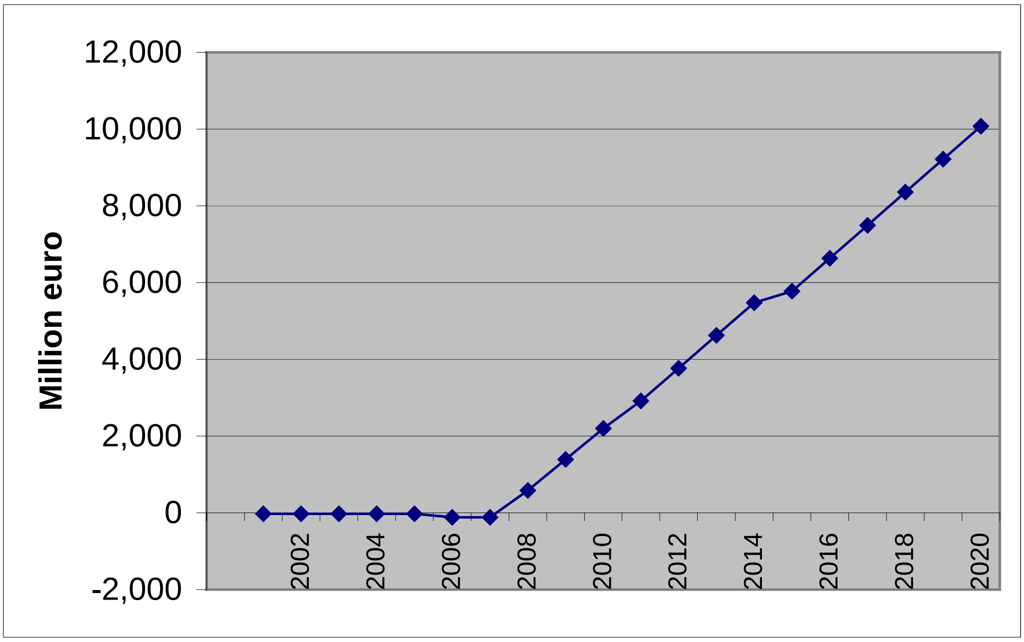

Figure 5.4-1: Profile of total annual net benefit (million € pa)

A larger scale focus on years 2000 to 2008 is given below.

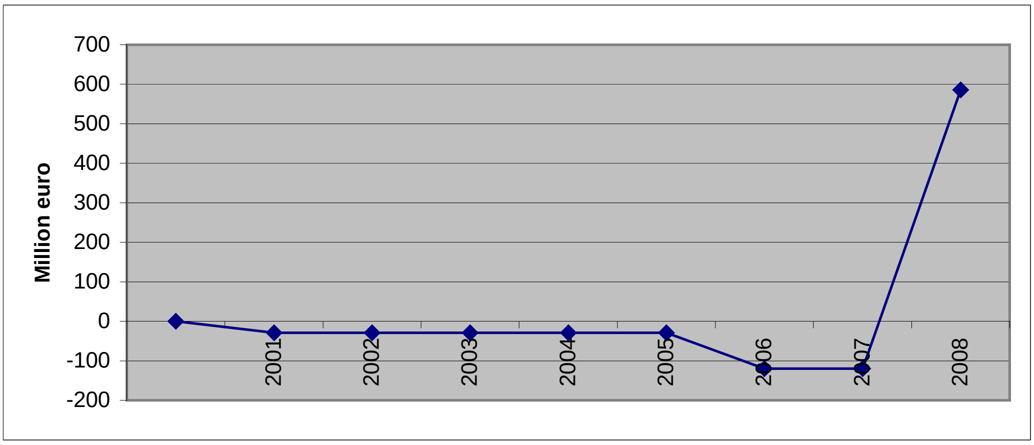

Figure 5.4-2: 2000-2008 profile of net benefits (million € pa)

Figure 5.4-3 gives a breakdown of the total annual benefits that have led to this result and illustrates how they are broken down by economic benefits (producers and users) and also social benefits.

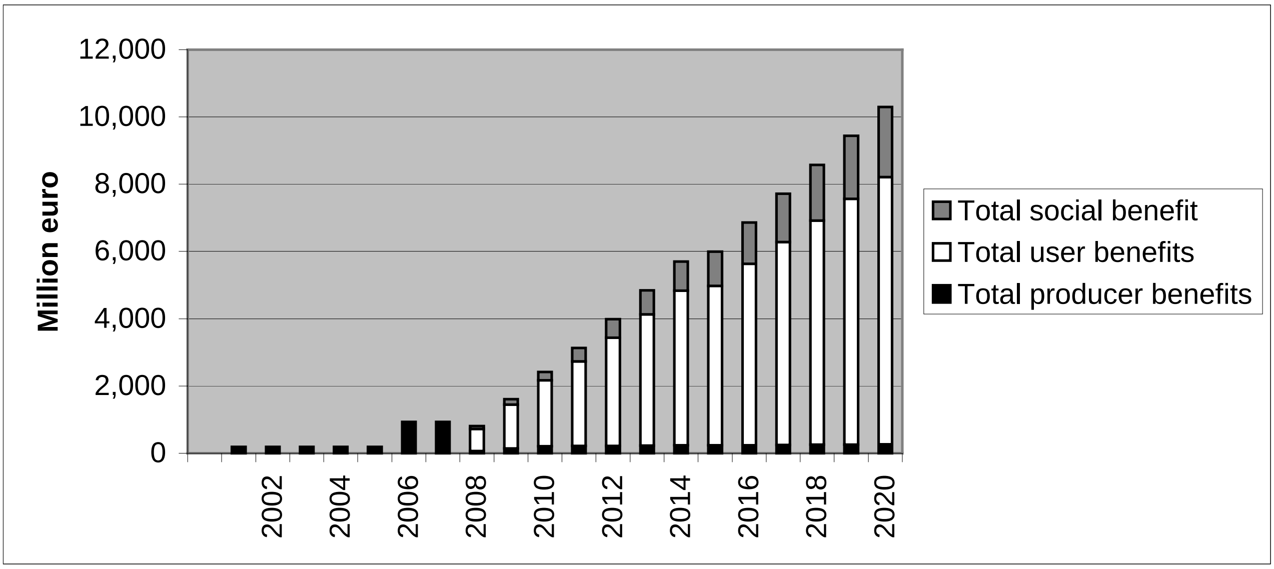

Figure 5.4-3: Breakdown of annual benefits (million € pa)

Figure 5.4-3 shows the growing dominance of user benefits (surplus) over producer benefits. This confirms the value of Galileo as a public good.

5.4.1.2 Sensitivity indicators

There are, of course, a number of uncertainties in the value of net benefits that can be estimated for Galileo. The accuracy of the investment costs is clearly a very important determinant. However, the underpinning data sets for benefit assessments have included (a) market estimates and (b) the assessments of benefits to users (user net benefits).

Figure 5.4-4 provides an illustration of the sensitivity of predicted net benefit value calculations, due to uncertainties in market and benefit prediction. It shows the net benefit profile from Figure 5.4-1 (derived from the "most likely" market figures) compared with the profile derived from the:

- "pessimistic" market predictions[2],
- the case where the estimated user surplus and social benefits have both been reduced by (an arbitrary) 30%, reflecting the uncertainty inherent in these estimates.

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[2] see § 2.1

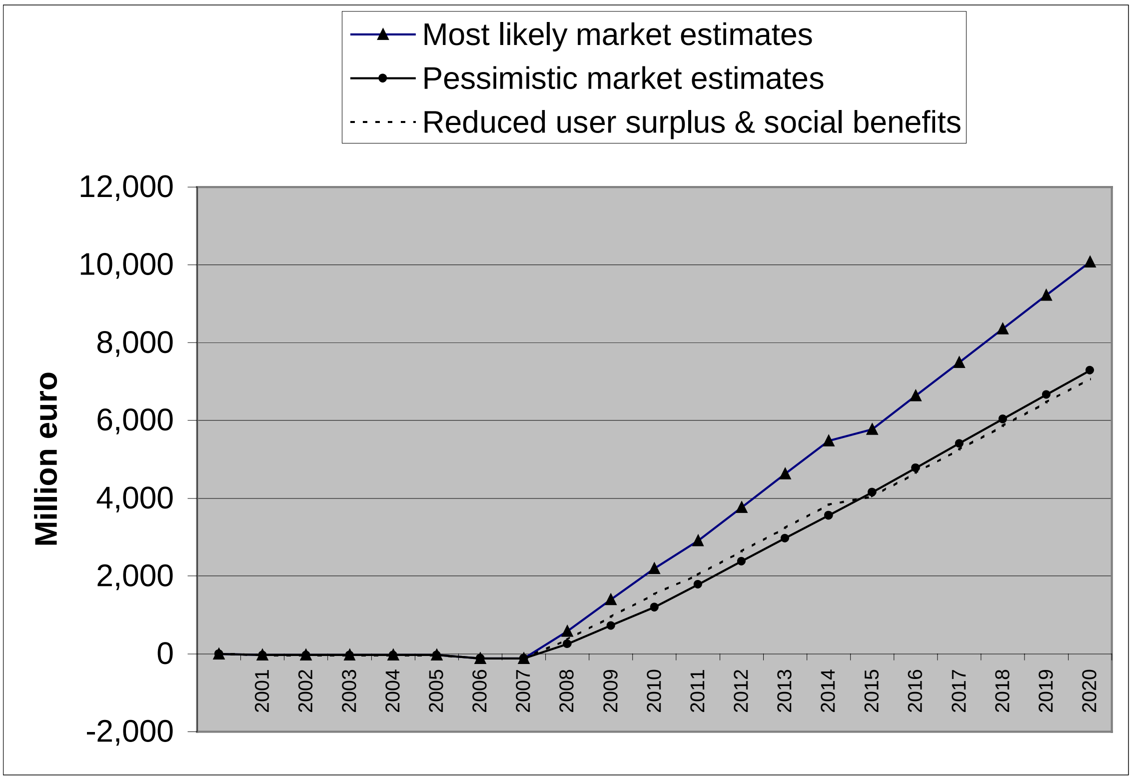

Figure 5.4-1: Illustration of sensitivity of net benefits to uncertainties in predictions of market size and estimations of user and social benefits (million € pa)

The more pessimistic market outlook scenario gives:

- IRR of 64% ,
- a positive NPV of €21 billion (at 5% discount),
- a positive NPV of €10 billion (at 10% discount).

The 30% reduced estimate of user and social benefits gives:

- IRR of 67% ,
- a positive NPV of €22 billion (at 5% discount),
- a positive NPV of €11 billion (at 10% discount).

Although the pessimistic market figures reduce the IRR from 75% to 64% and the 30% reduction in estimates of user and social benefits reduce IRR to 67%, the investment appraisal is still highly positive. It can therefore be concluded that the uncertainties inherent in the input data to the cost benefit analysis do not invalidate the overall outcome.

In terms of market and benefit figures, the presence of improved services from local elements has not been taken into account. However, the cost of implementing such local elements in Europe (i.e. over main cities, airports, harbours, etc.), which will be a matter of decision and funding at local level, can artificially be taken into account as "decrease of benefits". This decrease is completely covered in the above sensitivity analysis, when assuming a conservative total [2008-2020] value of some €1 billion over Europe (i.e. local elements represent a very small fraction of the 30% benefits reduction). In addition, full use of these local elements should increase further the European market and associated benefits.

5.4.1.3 Concluding remarks

The total economic and social benefits of Galileo to Europe are estimated to be 74 billion €, compared with a total investment cost of €6 billion [3] over 20 years. This results in a strong positive IRR of around 75%.

This very high IRR value includes the full range of producer, user and social benefits. These are the **additional benefits** to Europe - attributable to Galileo, when compared with the zero option. However, they do not take into account any displacement effects.

The growth in employment resources (man-years) is estimated to be an average of:

- 3,800 pa during the design and development phase,
- 19,000 pa during the deployment phase,
- 4,200 pa during FOC, by 2010,
- 5,200 pa by 2020.

The highly positive IRR's, combined with a strong set of strategic and political benefits for Galileo, provide a **compelling case for public sector investment**. Although caution must be applied at this stage of the work, given the uncertainties inherent in the data available for this Cost Benefit Analysis.

The strategic benefits are:

- development of a certified system under European civilian control to support the implementation of future common European policies;
- opportunities for developing greater political, economic and social cohesion across Europe;
- presentation of a stronger negotiating position with respect to foreign policy, relationships with third countries and international trade relations;
- maintenance of strategic industrial capability, capacity and know-how to build, launch and operate satellites to provide Europe with an autonomous access to space, as well the development of the down-stream industry including SMEs (small and medium sized enterprises).

In addition, the existence of a European satellite navigation service will also mean that Europe can be assured of a service even if GPS is unavailable for whatever reason. Europe’s dependence on navigation, positioning and timing applications will grow as the forecast number of terminals in use increases from 100 million terminals in 2005 to 370 million in 2020. It has been estimated that Europe will incur losses larger that the €6 billion [4] needed for the investment in Galileo, if there is a possibility that GPS is interrupted for more than 7 hours a year over the time period up to 2020.

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[3] This is made up of €3.25 billion in 2001-2007 and €220 million pa thereafter.

[4] This is made up of €3.25 billion in 2001-2007 and €220 million pa thereafter.

5.4.2 Programme cost overview

5.4.2.1 High Level Assumptions

The following high level assumptions have been made in the cost assessment process :

- The Galileo Infrastructure will be procured & operated by a PPP organisation known as the Galileo Operating Company.
- The Galileo Agency will be a 100% public organisation responsible for overseeing the activities of the GOC.
- There will be other organisations responsible for non-European regional components. Only typical costs can be identified for such regions as they depend on geography and politics. These costs are not costs to the GOC.
- There will be a number of companies offering local component services. Although the GOC could do this, it is assumed that it will not.
- Some other public bodies will be involved and will incur expenses e.g. the ESA technological development.
- Cost of EGNOS to AOC excluded.
- Cost of ongoing ESA technical developments excluded.
- All costs presented are in year 2000 Euro. No escalation is performed. However where costs are expected to fall, e.g. computers and telecommunications services, allowance for this is included but all figures are in year 2000 Euro.

5.4.2.2 Baseline Architecture

The top level cost summary for the baseline architecture is presented in Table 5.4-2.

Major cost categories	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**Total 2001-2007**	**Per annu. 2008-2027**	**Total 2008-2027**
Public Agency Management costs		1.5	1.5	1.5	1.5	1.5	1.5	9.0	1.5	30
Management costs of Galileo Operating Company	16	19	19	21	21	21	21	138	20	392
Initial infrastructure design, development, production and deployment costs	224	392	371	332	586	845	345	3096		
Operations costs	0	28	28	43	34	34	34	201	68	1370
Replenishment costs									174	3480
TOTAL	**240**	**440**	**420**	**398**	**642**	**901**	**401**	**3443**	**264**	**5272**

Table 5.4-2 Consolidated Top Level Summary Costs for Baseline Architecture

The cost of the initial infrastructure procurement (to FOC) is therefore approximately 3.2 Billion Euro and the total cost for the core Galileo activities to FOC is approximately 3.4 Billion Euro. Note that this latter figure includes the GOC management cost - this is the PPP approach; a standard costing for an institutional programme normally excludes institutional management costs and care must be taken when comparing costings.

The baseline infrastructure costs, corresponding to 3096 million Euro as indicated in Table 5.4-2, can be broken down as follows.

Main Items	**Cost (in million Euro)**
Overall Management	116
System Engineering	185
System Validation	76
Global Component – Space Segment	1094
Global Component – Ground Segment	637
Global Component – Launchers	738
Global Component – Other	94
EGNOS +	96
Local Component	30
User Segment	30
Total	**3096**

Table 5.4-3 : Breakdown of Infrastructure Costs

5.4.2.3 User Terminal Recurrent Cost Assessment

In the following Table 5.4-4, the selected representative applications addressed by Galileo user terminals are listed in the first column. Then, the current today’s reference price (for GPS equipment) is indicated in the second column for comparison purposes. In the next columns, the estimated prices for Galileo are indicated : firstly if the user terminal would have to be manufactured today (2000) and then in the next column with the price reduction available in 10 years (2010). However, these estimated prices are closely related to manufacturing quantities indicated in the next column for 2000 and 2010, since the scale factor is quite important for price determination. The last column indicated the proportion of the Galileo user terminal in the equipment bought by the user.

Application	GPS reference price	Galileo estimated price		Manufacturing quantity		Proportion of the equipment price
		2000	2010	2000	2010	
Car navigation and route guidance	<40Euro	<40Euro	<22Euro OAS single <31Euro OAS dual	200k@year	1 mio. @year	marginal
Personnel outdoor recreation	<250 Euro	<200 Euro	<120 Euro	50k@year	1 mio. @year	100%
Emergency caller location	<40Euro	<40Euro	<16Euro OAS single <23Euro OAS dual	> 1 mio. @ year	> 10 mio. @ year	10%
Commercial air transport (CAT-I)	3500-5500Euro	3700-5700Euro	2500-4000Euro	2000@year	3000@year	20-30%
Train control	-	-	2500-4000Euro	-	3000@year	100%
Marine navigation	<3 KEuro	<3,5KEuro	<2,2KEuro	500@year	550@year	100%
Land survey	<19 KEuro	<19 KEuro	<14 KEuro	100@year	300@year	100%
Time tagging	240Euro	<220Euro	<130Euro	10k@year	79k@year	marginal
Fleet Management (buses)	<2500 Euro	<2500 Euro	200-600Euro	2k@year	10k@year	100%
Hydrographic Survey	<20 KEuro	<20 KEuro	<12 KEuro	200@year	1k@year	25%

Table 5.4-4 : Price assessment of the reference Galileo user terminals

5.5 INTERNATIONAL CO-OPERATION

Galileo will provide, on a world-wide basis, location and time information to a large number of users, based on a civilian system.
To be fully accepted at international level, a close co-operation with other international countries is needed.
This co-operation can be based on technical issues (regional component of the system) but also based on specific regional or local needs as well as market issues (service providers).

For the time being, three non European countries contribute to the definition of the system : Canada, Israel and Russia.

5.5.1 Co-operation with Canada

This main co-operation topic is the definition of an American Regional element.
The study objective is to identify the Canadian GNSS needs and expectations, potential Canadian GNSS implementation participants and supporters, provide input to the process led by the European Union for the implementation of the Galileo system in the North American region, and make programme recommendations to the Canadian Space Agency.

The goal of the study is to identify meaningful strategic, industrial, and technical opportunities for Canadian participation in the development, maintenance and exploitation of the Galileo system.
A second phase will follow, to define and detail the activities that Canada could undertake in the Galileo programme.

5.5.2 Co-operation with Israel

This co-operation is based on two main activities :

- Definition of co-operation guidelines, with the analysis of identified Galileo User needs and comparison with user needs specific to the considered region and the definition of programmatic requirements. The contribution to Galileo programme will be based on the description of data specific for the considered region : geographical, political, organisational, legal and institutional.
- A pilot project, more dedicated to Civil Aviation purpose, whose objectives are to evaluate benefits for the management of the air traffic between Europe and the Middle East, using EGNOS/Galileo as the primary air navigation means during all flight phases and to present a preliminary evaluation of an intelligent Air Traffic Navigation System with a sophisticated decision support system to find in real time the best route for aircraft, while handling potential collision with other aircraft.

5.5.3 Co-operation with Russia

The activities were performed in order to provide an outstanding feedback on the main system and programmatic issues and will be also a tool for supporting the negotiations between the EC and Russia. An interaction with the other studies involving Russian industry in Galileo (GAFLEX, GalileoSat, EURORUSSE 3) has also been ensured.

The activities covered the 2 following topics:

- System activities :
    - System Analysis of the concept, interoperability and Use of LORAN and CHAYKA in conjunction with Galileo,
    - Time reference and reference frames,
    - Integrity concept and regional component for Russia,
    - SAR Secondary mission,
    - SIS definition,
    - Validation and Qualification.
- Programmatics:
    - Development logic,
    - Cost elements,
    - Industrial co-operation.

5.6 RISK MANAGEMENT PROCESS

5.6.1 Description of the process implemented on GALA

The implementation of a complex system such as Galileo requires the co-operation of several entities (industry, institutional organisations, etc.) at European and International levels. In order to ensure the successful completion of such a project, one of the key elements is an efficient project management at every level. Risks are an integral part of any project, but taking into account the complexity, the schedule constraints, the political and economical dimension of Galileo, they are a central part of Galileo management. A risk management process was therefore implemented very early in the GALA project in order to :

- keep Galileo risks within defined and accepted risk levels,
- strongly contribute to the overall project management through the project decision process (architectural trade-offs, programme feasibility, development logic, RAMS-dependability and Safety, etc.).

This risk management had to cover all the areas of the programme : technical, programmatic, financial, schedule etc.. Furthermore, in order to be successful, it had to involve all Galileo main actors : EC supported by GAST (Galileo Architecture Support Team), ESA, Industry, etc.

The Risk Management Process put in place on the GALA project was composed of four main steps:

Step 1: Risk identification:

Main inputs: definition of risk identification criteria and risk categories
Main output: list of potential risk scenarios (causes, consequences)

Step 2: Risk assessment:

Main Inputs: definition of consequence severity classes and criteria of probability of risk occurrence
Main output: "quantified" risks in term of criticality

Step 3: Risk Classification:

Main outputs : classified risks, **critical item list** and definition of **actions** for elimination or reduction of risk

Step 4: Risk monitoring:

Main objective : implementation, control and verification of actions for elimination or reduction of risk

One key element in this process has been the implementation of a Risk Management Team (RMT) which was composed of representatives of the principal contractors of the GALA project including GAST. The main task of this RMT was to implement the risk management process. It had further the task to monitor the evolution of the identified risks and to control the associated mitigation/recovery actions.

This section has essentially been produced using outputs of the risk management process under control of the RMT formalised in the so called document GALA Critical Items List.
It gives a synthesis of what has been drawn from an in depth bottom-up analysis of the identified risks with respect to the criteria defined for the Galileo programme or feared events.

The main outcome of the analysis is that causes appear to be common and recurrent to more or less all the criteria. It has therefore been found interesting to list these main causes and then to present the overall mitigation actions, which eventually can be proposed. Finally, global recommendations are drawn from these overall mitigation actions and a general conclusion is presented on the status of the implemented risk management process the results of which are presented in this section.

5.6.2 Risk Areas

The four main identified risk areas are defined hereafter together with their related causes.

The first one is directly related to the non achievement of technical and schedule objectives (and indirectly of certification, business and political objectives). This has the following causes :

- limited capacity of European industry to control critical technologies such as on board clocks or user terminals;
- requirements capture mechanism or requirements management system leading to a misunderstanding and a non fulfilment of the user's needs. This encompasses:
    - implementation requirements, including security and geographical constraints are not specified and qualified in time;
    - certification requirements including safety ones are not identified early enough in the requirements capture process;
    - certification process, procedures and supporting standards including these coping with reliability engineering are unknown.

The second one relates to the non achievement of business and financial objectives, the main causes for these being:

- difficulty in accurate market size forecasting so far into the future, and high competitive threats;
- non consolidated Galileo global cost assessment, in particular, due to incomplete RAMS (dependability and safety) feedback (redundancy, etc.) on system engineering, certification constraints not well anticipated, problem of consistency and incompatibility between different studies outcomes;
- missing Galileo services windows of opportunity, due to major Galileo programme delays.

The third main cause is related to the legal aspects with regards to the exploitation, operation and use of the system and its delivered services: the legal framework and institutional organisation schemes are lacking or are not well established at the time when the system becomes operational.

Finally the fourth one is related to organisational matters: a pro-active organisation at European level coping with specific management issues such as but not limited to project management, system definition co-ordination, security, safety and certification requirements specification and qualification, standardisation and communication with non European standardisation bodies, protection of Galileo signal structure definition, exploitation and operation of Galileo has still to be implemented.

5.6.3 Recommended mitigation actions

The following recommended mitigation actions have been derived to cope with identified risk causes :

- implement a rigorous requirements management system and define at European level an adequate Industry policy promoting research and development programmes supported by early trials in the identified critical area;
- continue intensive market survey activities and define a consolidated and justified approach for development logic taking into account all the Galileo constraints (signal international negotiation, windows of opportunity, technological risks, critical technology, etc.) and being compatible with Galileo objectives;
- start as soon as possible further work on the legal framework and institutional organisation definition;
- set up a pro-active European level Galileo Overall Management Organisation.

5.6.4 Main recommendations

The main recommendations which might be drawn from this synthesis are:

- The clear necessity to set up an overall efficient Galileo programme management structure federating the management of user's needs encompassing performance, security, certification and standardisation, encouraging Galileo market survey and promoting legal and institutional related organisational needs;
- The need for urgently defining a European Galileo Industry policy on which the above required management structure could rely on to promote an efficient world wide industrial competition strategy for the European industry.

5.6.5 Conclusions

The Galileo risk management process implemented on the GALA project has allowed to identify and to monitor Galileo main risk areas, essentially through the identification and the management of adequate risk reduction actions. Many of these need to be carried on during next phases of the programme.

So, the main recommendation for next phases is to set up and to continue a similar efficient Galileo risk management process.

6 CONCLUSION AND RECOMMENDATIONS

This section summarises the main outcomes of GALA study and provides key recommendations, taking advantage of the experience gained during the study.

6.1 MAIN OUTCOMES

6.1.1 Galileo services

6.1.1.1 User needs and market analyses

The user needs, providing the main guidelines to elaborate Galileo requirements, have been determined first by the definition and characterisation of 92 distinct applications. For each application, an analysis of the user needs have been performed, showing that the need for accuracy is 3 meters or more for 50%, and 1 meter or more for 80% of the applications. Concerning availability of the provided services, 90% require at least 99% availability and 47% require at least 99.8%. The analysis showed that key non-technical differentiators are expected from Galileo compared to GPS, namely : service guaranty, liability, traceability of past performance, operation transparency, certification, internationally recognised standards, interoperability with GPS and finally integrated service provision.

The market sizing analysed the period from 2010 to 2020, and determined the total market as well as the GNSS penetration factor and the Galileo market share to finally assess the so-called Galileo market size. The assessments have distinguished optimistic, most likely and pessimistic values. As a result, the total Galileo market, in terms of number of units, is estimated at 410 million in 2015 and 745 million in 2020.

From this analysis, the revenues have been derived, making the difference between gross revenues, corresponding to the general activity generated, and the net revenues, corresponding to the activity strictly attributable to Galileo. As a result, the total annual revenues in 2015 are estimated at 22.2 billion Euro for the gross revenues and 3.2 billion Euro for the net revenues.

6.1.1.2 Design requirements

The overall Galileo requirements have been derived from these analyses and from the identification of design requirements.

First, the proposed security policy identified the need for dedicated encrypted services for strategic applications to allow full availability in periods of crisis or conflicts.

Second, the integration of EGNOS has been determined following a two steps approach : first an optimisation of Galileo architecture, then an optimisation of the integration of EGNOS, in terms of services and in terms of architecture. A set of objectives were fixed, e.g. no impact on EGNOS development plan, guaranty of the continuity of EGNOS service. The optimisation proposed a phased approach, based on a unique step to accommodate GPS modernisation involving the new L5 frequency as well as Galileo integrity monitoring.

6.1.1.3 Legal and institutional requirements

Legal and institutional activities highlighted the need for defining and ensuring a guaranty of service. It concerns the mechanisms implemented a priori and a posteriori to prevent, inform (off line), alert (on line) or compensate failure, disruption or provision of a service not meeting all of its specifications. These mechanisms include certification, licensing, existence of a guarantor, compensation mechanisms and “jurisdiction/recourse mechanisms”.

6.1.1.4 Service definition

The definition of services needed a thorough analysis to determine a complete set of parameters necessary to ensure user satisfaction. These parameters are : signals to be received, potentially other systems to be used, coverage, environment (masking angles), accuracy, integrity, continuity, availability, safety level and level of service guaranty.

Four navigation services have been defined :

- OAS for mass market users, free of charge, based on dual or single frequency receivers, the performance being assessed for use autonomously and in combination with GPS, Loran or hybridised sensors.
- CAS1 for professional and scientist users, based on OAS frequencies with additional high rate data including integrity information valid world-wide and possibly local area data for a number of areas. This service is guaranteed, the performance being assessed for use autonomously and in combination with GPS, with local components and with a third frequency for centimetre-range positioning (TCAR).
- SAS for users where lives could be in danger, including but not limited to civil aviation. This service provides a high level of integrity, its use being certified and based on internationally approved standards. The baseline allows the service to be encrypted to ensure its availability even during times of crisis or conflicts, and to allow a full service guaranty and operator liability. Its performance fulfils current civil aviation and maritime standardised requirements world-wide, including integrity provision and taking advantage of regional overlay components, local components and combined use with GPS.
- GAS for governmental users, including military, police, fire, and users wishing a full robustness and availability during crises and conflicts. The control will be ensured by civil bodies and the performance is achieved globally, enhancements being provided by local components and possible combination with GPS.

Galileo also provides Search And Rescue (SAR) capabilities, with a payload onboard the MEO satellites ensuring a forward link from users to SAR Mission Control Centre, and a feed-back link from the Rescue Control Centre to the users via OAS, SAS and GAS signals.

The combination of navigation and communication means is highlighted, the baseline being to rely on existing and future communication systems.

6.1.1.5 Performance and traceability

Complete simulations have been performed to assess the final performance of all services and associated cases – global, regional and local coverage, use of other systems, hybridisation – and taking into account user environments in terms of noise, ionosphere compensation and multipath. This allowed as well to derive performance requirements at all levels – Mission, System, Components, User Terminals.

Traceability of all requirements have been ensured to allow a complete visibility and the possibility of requirement changes, using the DOORS tool.

6.1.2 Galileo system architecture

6.1.2.1 System concepts

A trade-off has been performed for the constellation, either based on MEO only, or on a combination of MEO and GEO navigation satellites. Identical performance and coverage requirements were assumed for the constellation sizing. The analysis of cost, performance characteristics, sensitivity to masking angles, programme risks and integration of EGNOS led to the conclusion that a MEO only constellation is preferred, not excluding GEO for continuation of EGNOS services and for Galileo internal communication purposes.

The integrity concept has been fully analysed to ensure optimised provision of Galileo and possibly GPS integrity information through Galileo MEO satellites. The concept allows regions outside Europe to develop their own integrity monitoring components and broadcast their integrity information through Galileo MEO satellites. The proposed concept is based on GNSS1 concepts, the broadcast being considerably improved, allowing instantaneous recovery of integrity status after a masking – essential for urban applications – and reserving slots in the MEO messages to broadcast regional integrity information.

The signal definition is based on 3 possible frequency scenarii, ensuring flexibility with respect to ongoing international negotiations with the United States and Russia, and to possible combination of services on the same signals, depending on user acceptance. The optimisation of the signal structure and the navigation message considered a variety of parameters, including robustness to interference and jamming, security policy, integrity Time-To-Alarm, Time-To-First-Fix. The outcomes have been provided in structured documents to ease future standards to be realised, namely Interface Control Document (ICD) and MOPS (Minimum Operational Performance Specifications).

6.1.2.2 Architecture definition

The overall architecture of Galileo is given, including Global, Regional, Local components as well as Management and Operating segments, user segment and other systems to be used in conjunction with Galileo.

The Galileo global component consists of the global space segment responsible for the space vehicle monitoring, control and command and the global mission ground segment responsible for the provision of navigation and integrity data.

The Galileo regional component is justified by the liability that some regions outside Europe will decide to take on the provision of integrity information over their territories. The architecture of such components is flexible, allowing each region either to develop its own dedicated monitoring network, or use a part of the global network and develop only their own integrity processing and control facilities.

The Galileo local component is based on the same concepts developed for GBAS, and is designed to achieve stringent accuracy and integrity requirements.

The user terminals have been designed for a set of receiver categories representing the huge variety of applications being defined.

6.1.2.3 Safety and security

The Reliability, Availability, Maintainability and Safety (RAMS) analyses identified a complete set of Hazards, from user point of view – Preliminary Hazard Analysis (PHA) – and from a system point of view – Functional Hazard Analysis (FHA). The derived failure scenarii allowed to derive requirements on the system and its components to counter such feared events. The analysis and the refinement of application mapping on services allowed to characterise appropriate RAMS levels on each service.

The security tasks followed a similar approach, identifying threats and subsequent functions to derive requirements on the architecture in order to bring the associated system vulnerability to an acceptable level. Architecture analyses provided a complete description of the key management and design activities defined all security modules, site protection and spectrum survey elements.

6.1.2.4 Support segment

Specific activities have been performed to define and assess the cost of the support segment necessary to ensure the availability of tools for system design, validation, safety and for the demonstrations towards various user communities and potential system investors.

6.1.3 Programmatic aspects

6.1.3.1 Development plan definition

The implementation plan first defined the main programme phases : definition, design and development, validation, deployment and replenishment. Then 3 scenarii were considered : a Final Operational Capability (FOC) with 30 satellites in 2008, a FOC with 30 satellites in 2008 with an Initial Operational Capability (IOC) with 24 satellites before 2007, and finally a FOC with 30 satellites in 2006.

The assessment of the scenarii considered a set of key parameters : In-Orbit Validation effectiveness, success of the deployment schedule, certification feasibility and operational capability effectiveness. As a conclusion, the third scenario is proposed to be discarded because of the various criticalities identified, and the scenario 2 is proposed to be the baseline due to its better certification feasibility and operational capability effectiveness.

6.1.3.2 Business and costs aspects

The cost of Galileo infrastructure up to the FOC is estimated at approximately 3.2 billion Euro. Target recurrent costs of user terminals are also provided.

Concerning Galileo benefits, the analysis considered the period 2001–2020 and provided annual supplier and user net benefits, as well as social benefits. Total benefits are estimated at 74 billion Euro over the period, from which 6 billion Euro shall be subtracted for the investment costs. Annual curves are provided, showing positive net benefits after 2008 and a predominance of user benefits over producer benefits, which confirms the value of Galileo as a public good. The result is an IRR of around 75%, and a high growth of employment resources.

6.1.3.3 Risk management

A Risk Management Team has been settled to identify all risks associated to the Galileo programme and manage them in terms of characterisation of the consequences, proposals for actions and monitoring of the evolution of each risk with time. Technical, programmatic, institutional, legal risks have been identified, the objective being to ensure a continuity of such activities during all the programme cycle.

6.1.4 International co-operation

International partnerships have been settled with Canada, Israel and Russia to develop future co-operation on regional components, user needs and market issues.

6.2 OPEN POINTS AND FLEXIBILITY

Galileo programme being at an early phase, it is of utmost importance to keep some flexibility in order to keep the programme risks under control.
This section identifies several key open points which need to be closed in the very next months. Then, it presents how, within GALA, some flexibility has been kept in order to address several aspects of the programme such as market, performance, technical as well as management or political/international issues. Finally, it will propose, in the form of recommendations, a flexible approach in relation to the Public Private Partnership considered in the frame of Galileo.

6.2.1 Open points that are to be closed

Some trade-offs on key points of Galileo system definition are still open which require urgently a decision. Indeed, postponing too much a decision on these topics will greatly impact the viability of the programme in terms of cost and schedule.

6.2.1.1 Service definition and signal scenarios

In the current results of GALA study, four types of services are envisaged : OAS, CAS1, SAS and GAS with almost the same level of technical performance (accuracy, availability, integrity and continuity) but non-technical differences (guaranty of service, liability, value-added service, robustness, etc.) due to the specificities of the market and the different user communities.
Due to the frequency spectrum limitation and system optimisation, three frequency scenarios have been defined. These scenarios are relying on different combinations of services : SAS is either separated from the other services, or SAS is combined with GAS or SAS is combined with CAS1.
It is however needed to take urgently some decisions on the services Galileo is to provide and on the characteristics of these services including more specifically:

- the encryption strategy (none in OAS, encryption of data only for CAS1, encryption of ranging codes for GAS, but still to be decided for SAS),
- the combination of services and associated frequency scenario that is largely depending on the results of international negotiations with the USA and the Russian Federation,
- the strategy for optimisation of signal structures : number of carriers per service, interoperability with GPS, interference levels outside the useful bandwidth, etc.

6.2.1.2 Full service provision schedule

The current definition of Galileo architecture offers a flexibility in the implementation schedule for full operational capability. Indeed, it is not needed to have all the system components fully deployed and validated for addressing the market. The provision of core services (PVT) can be anticipated w.r.t. FOC and the full service including integrity, certification, value-added data, etc. can be provided in a second phase.

Therefore three alternatives are proposed for Galileo FOC :

- FOC in 2006, but this is considered very critical,
- FOC in 2008,
- FOC in 2008 with an IOC in 2006

The objective for FOC/IOC shall be fixed rapidly in order to limit the risks of non achievement of schedule objective.

6.2.2 Current flexibility

The objective of this section is to describe the items within Galileo definition issued from GALA where a flexible approach is proposed.

6.2.2.1 CAS1 revenue generation

CAS1 service provision is devoted to generate direct revenues as a complement to terminal sales. As a baseline, the data broadcast through this service include integrity information which is the basis for a service guarantee approach and possibly differential corrections which will lead to an improvement of positioning, velocity and timing accuracy. Other value added data may be considered if it is attractive and if it fits within the data rate capability.

One key question related to CAS1 revenue generation is its viability when one looks at the lack of maturity of navigation market and the competitive offer of GPS and OAS services.

For this reason, OAS and CAS1 services share the same signals and CAS1 information data is encrypted so that only paying users (such as professional users) will have access to this service.

This approach is flexible as it will be possible not to encrypt the data and to provide them free of charge as part of an improved OAS service in case it is demonstrated later in the programme (even after FOC) that the CAS1 service is not viable.

6.2.2.2 Navigation message structure

The navigation message structure is designed in order to keep flexibility on following topics :

- The integrity alarm is relying on a concept of “Integrity Context Index”, informing the user that the integrity table has been changed. This concept is an optimisation of the GNSS1 integrity concept which is needed for non favourable user environments with a higher risk of masking effects : after a masking period, the user will be rapidly informed of any change in the integrity status of the system without having to download all the complete table and then, in most cases, the service will be kept available.
- The regional integrity concept is consisting in a regional check of the integrity of the system, computed by the regions themselves and broadcast within the Galileo SIS in dedicated channels. One key advantage of this concept is that the number of regions is not fully fixed and even after FOC, there will be a possibility for reallocation to new or additional regions.
- It can be noted that these regional channels, even if limited in capacity, are also open for transmission of regional information other than regional integrity.
- Based on this concept of allocated channels, it is possible to decide later if the global and/or specific regions are willing or not to provide information about the integrity of GPS and/or GLONASS system.
- The high data rate CAS1 service in E6 band also offers a flexibility for dissemination of commercial data and the content of these data is flexible to accommodate later commercial needs : the bandwidth can be shared and allocated to different paying user communities on a global or regional basis.

6.2.2.3 International contribution

The development of Galileo system is open to international co-operation and there are three potential levels of contribution for external countries or regions:

- The region/country can first develop a regional integrity processing facility : the measurements are provided by the Galileo Global component but, for liability purposes, the region can develop its own processing facility that computes and monitors the regional integrity status and broadcasts it as part of Galileo SIS via the Global Component;

- At a second level, which can be a complement to the first one, the region is deploying its own regional network of stations in order to increase its independence with respect to the global component;
- At a third level, a region or country could participate in the Global Component by providing sites and facilities for ground stations.

6.2.2.4 EGNOS integration

The proposed concept of EGNOS integration is based on a functional analysis and not on a physical reuse which would have been very stringent and would have raised many difficulties for upgrading hardware and software. This approach allows for a high level of flexibility.

6.2.2.5 Requirement traceability

As a result of GALA activities, a requirement traceability has been implemented so that it will be more efficient to manage the evolution of requirements, allowing the identification of all impacted specifications when a modification is envisaged or decided.

6.2.2.6 Safety levels

As a result of GALA safety analysis, a third level of safety has been added to the two current ones : “safety critical” and “non safety”. Based on the analysis of potential applications and of the mapping with the services, it is proposed to have indeed a “safety-enhanced” level as an intermediate one.

6.2.2.7 Security levels

Three points of flexibility are resulting from the GALA security analysis:

- As a result of the securisation of the system, different levels of security have been defined which offer more flexibility than a black and white approach,
- In the signal frame, the security message is not fully fixed and could be changed easily,
- The cryptographic modules embarked on board each satellite could be shut down in case of failure without having to declare that the satellite is out of service : the provision of non encrypted services could then continue.

6.2.2.8 Overall validation and verification

Many purposes have to be achieved regarding the overall validation of Galileo performances as well as the system verification. This will be done through the use of simulations, experiments, prototyping, etc. and finally tests/analyses related to the operational system.

GALA has proposed an initial approach balancing the use of these different means in line with many constraints and expected conditions. Flexibility is a key factor to cope with the events and risks inherent to the implementation of such a complex system.

6.2.3 Recommendation for additional flexibility

It is furthermore recommended to get a flexibility for the following topics.

6.2.3.1 PPP

The funding of the Galileo programme is open to a partnership between public and private contributions. This is reflecting the two-fold nature of Galileo system which is strategic and commercial. However, in such an early phase of the programme, it appears difficult to raise a real interest from private investors when the suitability of the performance of the future system with respect to non-mature user needs is not fully demonstrated.

Therefore, it can be noted that the actual private investment is not enough consolidated and therefore it is recommended that flexibility is kept in the private funding plan in order to allow for the consolidation of revenues.

6.2.3.2 Margin on satellite MCV budgets

The space segment cost is about 50 % of the system cost and it can be easily understood that there is a need for optimising and customising at maximum the satellite design.
However, due to remaining uncertainties on service definition (number of navigation services, number of carriers, dedicated navigation-related communication payload to be embarked or not, etc.), it is recommended to keep sufficient mass and power consumption margins in order to be able to implement to a certain extent modifications without having to redesign completely the satellite.

6.3 KEY RECOMMENDATIONS

6.3.1 Management

6.3.1.1 Organisational framework

The organisational framework shall be established in the very short term, identifying the main actors in Galileo and their respective roles. This is the necessary basis to define the responsibilities in Galileo, the associated liabilities and the subsequent legal framework. It is also necessary to determine the decision process without which the management of the programme and the control of planning and cost is not possible. This organisational framework is understood in a large sense, identifying both institutional and private bodies involved.

6.3.1.2 Decision process

A decision process shall be defined and agreed among the actors identified in the organisational framework. This decision process needs to be defined according to the programme development plan in order to limit the risk of delays.
Due consideration shall be granted to the identification of the right entity in charge of a given decision or supporting the decision process. The experience shows that a number of actors provide recommendations reflecting internal interests that are usually not the interest of the programme.
The independence of some actors is therefore of paramount importance.

6.3.2 Requirements

Due consideration shall be granted to the consolidation and the evolution of requirements for Galileo.

6.3.2.1 Monitoring of user needs and markets

The continuation of user need monitoring and market analyses, which provide the basis for Galileo requirements, is highly recommended due to the uncertainty of current figures. First, this is due to the difficulty to provide figures that should be representative of the coming 20 years. Second, the situation evolves rapidly : new applications are found continuously, the technologies implemented in user terminals and in communication means improve constantly. Finally the penetration of GPS evolves according to user interests and depending on GPS improvements, like the addition of a second frequency for mass market users (L2).

6.3.2.2 Legal framework

The activities defining the legal framework have to be deepened, due to the number of aspects to be addressed, the impacts on the system architecture, and finally due to the time usually needed to achieve agreements at European and possibly at international levels.

The guaranty of service needs to be accurately defined and implemented, which is of paramount importance as it is one of the key differentiators with respect to GPS. As proposed, a guarantor shall be identified and compensation mechanisms shall be defined to allow an adequate management of user claims. These mechanisms shall be based on the results of a detailed analysis of financial risks performed by insurance companies.

The legal framework is needed before defining a liability framework, which has impacts on the system definition, as an example in the implementation of the recording function – archiving of signals and data – to be used as a means of proof in court and as an investigation capability to locate the origin of failures impacting the characteristics of the service delivered.

The importance of a convention on satellite navigation needs to be acknowledged and the way forward to be defined, probably starting by the establishment of a European Directive.

6.3.2.3 Security and safety

The security policy and its implementation for each provided service needs to be clearly settled and agreed. Clarification is highly needed on the security functions proposed for the Safety of life Access Service (SAS), distinguishing data authentication, data encryption and ranging code encryption.

This clarification is necessary to finalise the definition of Galileo services, and namely the implementation of several services on the same signals.

Due attention shall be paid to keep enough differentiators between the services to guaranty an adequate answer to the needs of all user categories. It is recalled that Galileo is based on a service approach and not on proprietary approach, where signals are defined by a small set of specific user communities.

A significant effort shall be granted to the consolidation of RAMS analyses to achieve a good confidence in the redundancy needed to achieve the required performance.

6.3.2.4 Standards

Standards have to be established, and approved by the relevant international bodies. This is a key factor for Galileo international acceptance. All standards need to be addressed. For example, standards are currently established for the implementation of GPS receivers in the telecommunication networks.

Due consideration shall be granted to the specificity of Galileo in that area. Indeed, international bodies provide standards from their own, like ICAO for specific civil aviation equipment. Due to the multi-modal nature of Galileo, a process shall be established to ensure that these standards are fully in line with the requirements placed on Galileo.

6.3.2.5 PPP

The potential private investment on Galileo needs to be clearly defined, namely in terms of sources of revenues and planning of investments allowing to get the necessary confidence in these revenues. The current PPP approaches do not show adequate maturity, and seem to be maintained to ensure that the private sector will be considered as an effective partner in the decisions on the programme. This is a fully valid request due to the major commercial interests of Galileo, but it brings a risk in Galileo funding.

Additionally, it is thought that the private sector has a major role to play in other areas than private funding : market survey, service definition for mass market users, independent support to overall system definition.

6.3.2.6 Traceability

It is highly recommended to maintain and consolidate the requirement traceability implemented to ensure the visibility, the origin and the justification of each requirement placed on Galileo. This is of growing importance in the course of the programme, where the scope and the complexity of the requirement are increasing. This is needed to have visibility and understanding of the compliance of defined system segments and elements with respect to requirements.

The traceability has constituted a very significant amount of work, even using a state-of-the-art tool such as DOORS, allowing a remote access through internet by all parties involved in this process.

6.3.3 System and architecture

6.3.3.1 User technologies

A key area to be continued and deepened is the monitoring of user technologies that will arise when Galileo is operational. Evolutions of signal processing techniques, hardware capacity and hybridisation sensors like inertial components need to be carefully considered to ensure the optimisation of the overall system, including the infrastructure and the user terminals.

6.3.3.2 System configuration

The system configuration needs to be monitored to ensure the full consistency of the system definition, and allow an adequate management of changes in the requirements and in the subsequent impacts on the system definition.

6.3.3.3 Implementation

Due consideration shall be granted to Assembly, Integration and Validation (AIV) aspects, Qualification needs, Deployment and operations of the system, certification plan and Integrated Logistic Support (ILS). These aspects have very significant impacts on system development plan and cost assessment. In that sense, the separation of the global component into a “classical” space segment and an “advanced” mission segment is very important. Indeed, the space segment will allow to provide “core services” (navigation functions without integrity and without encryption features, for example) with a limitation of risks, and will be qualified first. The mission segment will allow to provide the “full services” and will be qualified later, making use of the space segment.

6.3.4 Programmatics

6.3.4.1 Monitoring of development plan

The development plan as currently defined shall not be considered as fixed, and a continuous monitoring shall be implemented to monitor the critical path, detect any possible delay/drift and propose necessary recovery actions.

6.3.4.2 Risk management

The management of risks is a continuous activity that shall be pursued to assist the management, proposing actions to limit the impacts of any identified risk. Risks shall be understood in the very large sense, including technical, programmatic as well as management risks.

6.3.5 Awareness

6.3.5.1 User communities

Awareness of user communities, like ICAO or IMO, is of prime importance for acceptance of Galileo by them and, indirectly, as examples for other user communities. Namely, the GNSS Panel needs to be fed by all necessary information and explanations, especially for aspects where Galileo offers differences with GPS. Indeed, the experience shows that even significant improvements offered by Galileo may not be welcome due to the fact that they incur changes in the standards and habits taken with GPS.

6.3.5.2 International negotiations

International negotiations shall be continued and consolidated with predefined objectives, mainly in two domains.

First, in the frequency domain, where negotiations with US representatives shall bring enough confidence in the possibility to use GPS L1 and L2 wide bands. Also, discussions with a number of countries shall be continued to ensure the success of the next ITU WRC in 2003.

Second, to achieve concrete initiation of studies from international partners in order to define their intended contribution to Galileo programme. It is highlighted that the architecture has been defined to allow for many levels of contribution commitments, from the development of applications, independent regional monitoring facilities (using Galileo monitoring stations or independent ones) to finally a direct contribution to Galileo global component itself, which will represent a key advantage technically – suitable site locations – and financially.

It shall be noted that a successful integration of EGNOS into Galileo is a key factor to show to US and Japan the possibility to contribute to Galileo without impacting currently developed GNSS1 components.

In that domain, the initiatives taken and the messages delivered to potential international partners concerning EGNOS extensions and Galileo awareness shall be harmonised.

6.3.5.3 Business development

Cross activities will be a key factor for a successful integration of Galileo in everyday life. Namely, integration of Galileo in mobile telephones and in cars, can have impacts on Galileo system definition and need to be analysed deeply.

Also, preliminary developments have to be initiated, making use of GPS to allow to get a concrete feedback on potential growth factors of a number of key applications.

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