

The European Dependence on US-GPS and the GALILEO Initiative

1. Positioning and Time – The US predominance in new market segments of growing commercial and strategic significance

Knowledge of accurate position, velocity and time is fundamental to improving the efficiency of almost all activities.

The experience of GPS has demonstrated the advantages of satellite navigation to the extent that GPS is regarded in the USA as the fifth utility¹, alongside water, electricity, gas and the telephone. US military and civil users have developed a considerable dependence on the system. The military are reliant, to a significant extent, on satellite navigation as an aid to accurate weapon delivery and effective command and control. Civil applications are steadily increasing, especially for personal use in vehicles and mobile phones, and are becoming a fundamental component of the Global Information Infrastructure.

One major concern for GPS users is the vulnerability of the navigation signal. Several cases of GPS service disruption have been reported over the past years, which had many different origins, including unintentional interference, satellite failure, signal denial or degradation by US authorities. As an example, in 2000, no navigation signal could be received for 18 minutes over the territories of Oklahoma, Kansas and Nebraska. This service disruption was due to satellites malfunctioning.

Intentional interference has also to be considered, as GPS uses very low-power signal and GPS jamming does not require complex equipment².

Further to a Presidential Decision Directive, issued by the White House on 22 May 1998, the US department of transport undertook “*an evaluation of the vulnerability of the national transportation infrastructure that relies on GPS*”. The Final Report, known as the Volpe Report, dated 29 August 2001, identifies the degree to which GPS has been taken up by the civil community in the USA. The report identifies the rapid rise in the use of GPS in the national transportation infrastructure to improve the safety of the transportation systems and increase their operational effectiveness³. It highlights the increasing reliance placed on GPS as a radio navigation aid, a source of

¹ The White House, Office of the press secretary. Press briefing by assistant Secretary of Transportation, Gene Conti, 1 May 2000

² GPS jamming equipment is already available within the Russian market.

³ Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System, Final Report, 29 August 2001, p1, para 1.2 (2)

accurate vehicle positioning as part of new improved surveillance systems; and a timing reference for much of the national power grids and telecommunications networks.

In Europe, the EC White Paper on European Transport policy for 2010 identifies GNSS as a critical technology that could revolutionise European transport infrastructure⁴. The reliance of European transport infrastructure on GNSS is likely, at a minimum, to mirror that occurring in the USA.

If Europe were to decide not to develop GALILEO further, it would leave Europe completely dependent on GPS.

This paper examines the implications for Europe of relying totally on GPS.

2. Positioning & Time and Europe's fast growing Dependence on GPS-Navstar

2.1 Social & economic dependence

Satellite navigation is becoming more widespread across many different market sectors. This includes "old economy" segments such as surveying and mapping, construction and mining, air/land/sea transportation, together with the "new economy" for Internet products and services, mobile computing and wireless communications.

The largest growth in this market is likely to come from the personal use of GNSS, in vehicles and possibly in mobile phones. Regulation concerning the automatic location pinpointing of mobile phone users making emergency calls, will also drive this market.

The US decision to provide the GPS standard positioning service free of charge and to discontinue the selective availability, (the intentional degradation of the GPS signal) is also a driver for the mass-market applications. The new level of accuracy – 10 meters instead of 100 m – will encourage development of new products and will accelerate the transition of GPS products into the mainstream. There were more than 6 million users of GNSS in Europe in 2001 and studies have estimated that this will grow to over 250 million by 2020 (ref to annex 1). World-wide, this figure is expected to reach 800 million users. This implies that, in the foreseeable future, the personal use of satellite navigation will become as ubiquitous as today's use of the mobile phone. As with mobile phones, the consumer reliance on satellite navigation will turn into dependence, as their use becomes an essential tool for business and daily lives.

GNSS will progressively penetrate a wide range of applications, some undetectable by the end user, which will make GPS dependence a progressively hidden problem. Moreover, for the numerous emerging applications, especially in highly competitive domains, the temptation will be to rely only on GNSS for cost

⁴ Commission of the European Communities White Paper – European transport Policy for 2010: time to Decide, COM (2001)370, Brussels 12 Sep 2001, p101

effectiveness. Therefore it can be anticipated that a GPS service disruption, for any intentional or unintentional reason, will generate dramatic economic and organisational consequences in developed countries.

The capability of GPS to degrade the accuracy for mass-market users was deactivated in May 2000, but the capability of reactivating it has been maintained, for the near future, as it will be implemented on modernised GPS satellites. This capability is stated to be an answer to security concerns; therefore one could imagine that such a reactivation will be decided with a very short prior notice in the best case. The economic consequences can be expected to be high due to the fact that people are progressively getting accustomed to the current accuracy and will, probably unconsciously, rely on it.

GALILEO under European control

The deployment of GALILEO as a second, independent and interoperable satellite navigation system, will ensure that European investments in the major market and user areas described above are not solely dependent on the US controlled GPS. Therefore, the introduction of Galileo will bring about an increase of the navigation consumer market.

Given the wide range of applications and geographical areas involved, 'individual' ground-based solutions for each would be expensive and inefficient. The space-based solution offered by GALILEO for navigation represents an effective solution, removing the dependence on GPS in a cost effective manner. The key issue is that, by its very nature, a satellite-based solution will support many different applications at the same time, thus making it a cost-effective overarching solution for aviation, marine, and road transport as well as for professional applications (e.g. timing, precision surveying) and personal infomobility.

2.2 Transport policy, European regulation and safety applications

It is anticipated that future EU regulations and decisions will increasingly depend on the availability of a certified satellite positioning system, with sufficient level of control from EU. That is likely to be the case for the implementation of the Trans European Network. Galileo will also assist in the implementation of a broader set of common European policies, notably agriculture, fisheries, regional development and environment.

Satellite navigation was identified as an essential tool for implementing the European Transport Policy. To meet the obligations of EU Directives for safe transport of People and Goods a GNSS is required to provide "guarantees of service" and carry "liability" commitments. To shift the balance between transport modes is likely to require regulation and the imposition of a transport pricing strategy. Both these aspects require the EU having control of one GNSS system.

The European Union Policy regarding GNSS has been defined in two steps. The first step has been to develop a monitoring system called EGNOS allowing a safe use of GPS for safety critical applications. The second step, in order to avoid keeping the EU dependant on GPS, through EGNOS, is to develop Galileo as an independent and

interoperable system.

The ability to change the balance between road usage and other modes of transport by the introduction of regulation or charging mechanisms based on GPS not under EU control does not appear sensible. It leaves Member States vulnerable to US imposition of charges.

The Volpe report, as mentioned in Section 1, highlights concerns over the vulnerability of GPS to unintentional and intentional interference. This confirms the need for improved robustness in safety of life and regulated applications since GPS is inherently vulnerable (See annex 2).

As a system based on the European Union and Member States concession and operation under European law, GALILEO can provide a legal framework for law enforcement in Europe (road tolling, etc.).

Certain Galileo services, such as Safety of life and commercial services, will be provided with guarantees of performance and the operator will be liable to compensate the users where this performance is not met. Galileo therefore is a major factor in allowing Europe to effectively implement the EU transport policy objectives.

GALILEO will reduce the risk of disruption from unintentional interference by providing a set of additional frequencies, whose bands have been allocated to satellite radio navigation systems by ITU during WRC 2000. Similarly, unintentional interference on all RNSS bands will be very unlikely.

Bringing a vital contribution to the mitigation of potential unintentional disruption, GALILEO will be the enabler of a general use of satellite navigation for numerous applications, which are currently reluctant to use radio navigation signals as a primary means of navigation. This will have a substantial economic impact for many applications and will introduce sufficient confidence to avoid implementing traditional and expensive backup systems (inertial systems for navigation, atomic clocks for synchronisation, etc.).

Advantageously, GALILEO is being designed at a time when these concerns are being highlighted, which allows the implementation of mitigation measures within the system itself. The key example highlighted in the Volpe Report as a recommendation, is the users awareness that can be satisfied through performance monitoring: “*systems and procedures to monitor, report, and locate unintentional interference should be implemented or utilized in any application for which loss of GPS is not tolerable.*” In this respect, GALILEO will provide “service guarantees” which, together with the integrity monitoring, would broadcast disruption awareness messages to the users within the signal in space.

Intentional interference

GALILEO will bring necessary improvements in respect of intentional interference, with the provision of a Public Regulated Service (PRS), the signals of which, using large bandwidths and being encrypted, offer significantly better support against intentional jamming, especially code jamming, and spoofing. The PRS is a civil secured service that can be offered to governmental and strategic civil users.

2.3 Time Reference and Time synchronisation for digital communication networks

Accurate time referencing is fundamentally important to the performance of digital networks that use high-speed data transmission systems, such as those used by fixed and mobile telecommunications systems, as well as digital broadcasting and the internet. Timing slips (between receive and transmit clocks) result in repetition or deletion of data, which in turn can lead to loss in the service quality of voice, fax or video transmissions or will require re-transmission of data or key codes. The overarching implication is degradation in network capacity/throughput.

For timing applications, the seamless availability of the co-ordinated Universal Time (UTC) today is entirely based on the availability of GPS over recent years. Since satellite GPS is the most cost efficient way to distribute time, most of the alternative means have become, or are in the process of becoming obsolete. The distribution of the world's time base therefore is highly dependent on the availability of GPS, which in itself puts a high risk on the reliance on single systems availability.

The significance of this issue is highlighted in an important article recently published by the Bureau International des Poids et Mesures (BIPM), Sèvres, France⁵:

“The American Global Positioning System (GPS) has served the principal needs of national timing laboratories for regular comparisons of remote atomic clocks for the last two decades. Single-channel GPS C/A-code common-view time transfer is, however, barely sufficient for comparison of today's atomic clocks within a few days, and certainly not sufficient for comparison of clocks currently being designed. For this reason the timing community is engaged in the development of new approaches to time and frequency comparisons, including techniques based on multi-channel GPS and the Russian Global Navigation Satellite System (GLONASS) C/A-code measurements ...

The introduction of GPS has led to a major improvement of world-wide time metrology in precision, accuracy and coverage. With GPS operated in single-channel common-view C/A-code mode, time comparisons can be performed with an uncertainty of a few nanoseconds, ...”

GALILEO will improve the global precision timing infrastructure provided through GNSS.

With its high number of high-precision clocks on-board, GALILEO will inherently form an integral part of the global timing and time synchronisation infrastructure and will complement GPS and GLONASS. GALILEO's emissions are controlled by high-precision atomic clocks. Receiving these signals and comparing GALILEO's clocks with the other 220 terrestrial clocks will provide a major improvement in accuracy

⁵ “Time Links for the construction of the TAI (international atomic time)”, J. Azoubib and W. Lewandowski; Bureau International des Poids et Mesures, Sèvres, France (NAVSAT 2001, Nice, November 2001)

and system robustness as it will complement GPS in this role. As a result, the overall robustness of the global time provisioning network will also significantly be improved

One major effect is that even in the event of a failure of GPS the performance of the communications infrastructure will not be adversely affected.

However, by doing so, GALILEO is less an issue of overcoming the dependence of GPS but much more a sign of Europe accepting a fair share of the burden of European and global service infrastructure.

2.4 Political dependence

To remain dependent on GPS means that Europe will be dependent on US policy in this area. This is outlined in a range of documents and is subject to change without reference to European requirements

The analysis of the available official US documentation⁶ indicates:

1. US determination to maintain GPS as the dominant satellite navigation system.
2. GPS will be provided free of direct user charges, but *it does not rule out charges levied against states*.
3. Specific authorisation to use GPS remains with the Deputy Under Secretary of Defense for Space of DOD.
4. US cannot share ownership of GPS with a foreign power⁷.

The fact is that the US not only controls the GPS infrastructure and operations, but also controls the users who can have access to it. The US is therefore in control of the current and future performance of GNSS and the timing of changes to this performance. This may not be consistent with the requirements of Europe. As our economic dependence on GPS grows, Europe can be held to ransom on all issues related to its use of GPS and might be obliged to pay governmental levies to the US in the future. Europe cannot accept this.

A complementary, independent and interoperable GNSS system – Galileo – is essential to neutralise these concerns.

⁶ Annex 3: March 1996 Presidential Policy statement for GPS; Space Daily News of the Pentagon letter to EU Member states; Civil Military Interface Study

⁷ Interpretation of the 1998 (HR1119) National Defence Authorisation Act Section 2281

2.5 Technical and industrial dependence

European GNSS product, applications and value added service provider companies currently command only a very small share of the global GNSS market.

US companies will continue to argue that there are changes to be made to GPS that non-US companies will be unaware of. European industry will find it difficult to expand business in such an environment. If, as is likely, the use of encryption and adaptive antennas enter use for critical civil users then the US will have a total monopoly on R&D and manufacture. European industry will be possibly be excluded other than as licensees.

The scope for growth of European companies in the GNSS market and consequently the reduction in European dependence on US technology and US industry, depends on two main factors:

- Increasing market share in the existing navigation market
- Maintaining existing market share in a larger global market for navigation products, applications and services

The planned development of Galileo will contribute substantially to the achievement of each of these two opportunities for growth in European industry.

European Commission funded studies during the definition phase for Galileo indicate that the global market for GNSS products and services based on GPS alone will reach €9bn annually by 2010, rising to €17bn annually by 2020. The introduction of Galileo will increase this overall GNSS market size to €12bn annually in 2010, rising to €28bn annually in 2020. This growth in market size represents an opportunity for growth in the European product, application and value added service provider industries.

When considering the market share achievable by European industry, one must consider what has already happened in the United States in the development of the GPS based GNSS market. The US controlled GPS system, coupled with the injection of development funding by the US government, has meant that US industry enjoys a dominant role in the GPS based GNSS market place. This has resulted in a very low market share for European companies. The introduction of a European controlled infrastructure, coupled with a similar stimulus to European application and receiver development, will mirror the historical evolution in the US.

The overall effect of introducing Galileo as planned will therefore significantly increase the market addressable by European product, applications and service provider companies, as well as dramatically increase the achievable market share of this larger market.

In addition, Europe must maintain the industrial capability and capacity to build, launch and operate satellites for navigation and timing purposes and also for telecommunications, meteorological and scientific exploration uses. From this perspective, Galileo will pose a number of challenges in design, manufacturing and certification that will help Europe to further develop its industrial capability in the future. The development of Galileo will ensure that Europe's capabilities in the fields of space qualified atomic clocks and volume parts procurement for multi-satellite constellations will be enhanced and dependence on US suppliers and technology reduced.

GALILEO will improve security for European investments and elevate European industries in innovative market segments.

With more and more of such spectacular commercial advantages for European investments, the US tax payer might quite reasonably consider that Europe should be required to compensate in one-way or another.

Thus, eventually Europe will quite probably have to pay for the provision of Navigation services by some means. If so, then European money should more appropriately be invested into European industries.

2.6 Scientific dependence

Earth exploration and research on macro-geological developments such as the development of global climate, ozone layer, and weather predictions highly depend on precise timing and positioning information to derive the right interpretations from sensors on ground as well as in the air and space. The importance of these measurements for humankind can be estimated by key research activities such as the measurement of continental shifts and its impact on earthquakes and volcanic activities.

All measurements rely mainly on the reliable availability of a high precision positioning and timing signal to place sensors in remote places. Such sensor networks are implemented to permanently measure water quality or pollution, as well as climatic long term impacts.

Together with GPS GALILEO will support the research of global phenomena and environmental disaster protection.

With the operation of GALILEO, Europe will substantially support the mandatory infrastructure that enables these important research activities. The availability of precise positioning is also a key support element of the European scenario for Public Protection and Disaster Relieve (PPDR).

2.7 Security dependence

All European NATO countries rely on GPS “Precision Position Service” (PPS) for their military applications. The modernisation of GPS will raise several questions, as the implementation of the new military code will allow denying selectively the GPS service to a group of users, or to a region. As a consequence, a large number of civilian users could have access to secure services, since the system will have the capacity to deny the GPS signals, as required by security reasons. . One particular concern is that with the modernisation of GPS, the European industry will not be able to build GPS receivers for the reception of military codes. Additional GALILEO benefits

3. GALILEO unique features

GALILEO and GPS will be interoperable which will improve the performance of satellite navigation in general, in a transparent manner for the user. In addition, GALILEO will cover GPS shortfalls, namely:

- **Service Guarantees.** An important differentiator is that GALILEO will, unlike GPS, offer a service guarantee for **certain types of civil users** in terms of accuracy, availability, continuity and integrity of the signal for certain types of services such as commercial services and safety-of-life services. The service guarantee would be an integral part of service level agreements that could be concluded between the GALILEO operator, the service providers and users. This legal framework will add to the confidence of users in the system and create an appropriate basis for compensation in case of liability for improper functioning. Furthermore, as GALILEO will be an independent European system under civil control, the necessary liability mechanism can be set up in an autonomous way. This also means that the shortcomings of GPS in this regard (such as potential barriers for claims against the US government as GPS owner) can be avoided.
- **Integrity Monitoring⁸.** Integrity on global installation for safety of life services will also be in a service guarantee environment. This will increase the overall safety, in particular in aviation, because the Time To Alarm of less than 10 s will help users of standard commercial services to react rapidly to malfunctions. It also provides for a transparent tool allowing assessment of performance in the light of the service guarantee. This would also facilitate in determining that the GALILEO operator is not liable for damages not caused by a wrongful or absent signal in space but by other factors such as human error. Furthermore, as GALILEO will be an independent European system under civil control, the necessary liability mechanism can be set up in an autonomous way. This also means that the shortcomings of GPS in this regard (such as potential barriers for claims against the US government as GPS owner) can be avoided.
- **Improved service performance and signal.** The GALILEO signal in space is designed to bring significant improvements when used in new applications, such as GSM and UMTS networks, with a higher signal strength. GALILEO will answer the needs expressed by many users to have guaranteed performances, to which the GALILEO operator will commit, based on auditing mechanisms. This need is of paramount importance for safety related applications.
- **Search and Rescue.** The Search and Rescue service on board the GALILEO will also contribute to security operations. It will significantly improve the

⁸ Integrity monitoring by the system will allow users to be warned if the signal cannot be trusted.

existing Search and Rescue system by detecting alerts in near real time, and locating them with an accuracy of just a few meters.

3.1 Combined GALILEO and GPS features

- **Performance improvements**

The quality of any satellite navigation service depends crucially on the receiver having a direct line to a number (preferably three, in a triangle) of satellites. A widely quoted assessment of the effect of adding GALILEO to GPS is that it would increase the coverage of the service from 55% to 95%, notably in urban areas where most mass-market applications are developed.

- **Response to severe requirements**

For security and safety of life applications, the European civil aviation authorities, represented in the EOIG group, have concluded that two satellite navigation systems in the future world wide architecture of GNSS are mandatory to achieve the required level of reliability. Consequently, the availability of both GPS (augmented with EGNOS) and GALILEO, with the compatibility and interoperability requirements of users of the navigation and integrity services, appears as a sine qua non condition for the structural development of the use of the satellite navigation technology in a safe and highly reliable way. Thus, having two independent but interoperable systems will be of benefit to Europe, the US and all other countries.

4. Conclusions

Importance of GNSS applications

The knowledge of precise timing and positioning, velocity of people and goods impacts and transforms increasing numbers of sectors of activities. Different ground based technologies have been and are still used to fulfil these needs. However it is the availability of the Global Positioning System, GPS that has lead to an in depth penetration of all sectors of the society. While military by nature the GPS, operated by the Department of Defence of the United States, has been open to civilian use. Quite logically the US economy benefits directly from the US investment and civilian applications and benefits from a technology largely supported by military budgets. As a consequence a world-wide dependence results from this de facto monopoly. This applies particularly to Europe where no equivalent space systems exist. This dependence is economic: Europe being not able for the time being to benefit from the

expansion of the market; it is also strategic as more and more critical applications rely on this new technology.

This situation has led the US administration itself to analyse the consequences for US of dependency on Navigation. The resulting analysis, the Volpe Report, indicates the vulnerability of the system to unintentional or intentional interference, which may be of particular importance for the safety of critical applications.

The European dependency is similar and aggravated by a dependence on a foreign system

European strategy towards GNSS

It is in this context Europe has already decided the implementation of the European Geostationary Navigation Overlay System (EGNOS) as a joint effort between the European Commission, the European Space Agency and Eurocontrol. While limited in scope, EGNOS has contributed to limit the dependence from GPS and opened the way for the second step towards autonomous Europe.

This has led the European Commission and the European Space Agency to start the implement of the second phase namely GALILEO. During the GALILEO definition phase all aspects of this complex programme have been analysed: institutional, economic, technical, operational, legal: this process has been initiated in 1998 and concluded end of 2001.

In particular it has been concluded that “GALILEO should be implemented as a civilian system independent from GPS but interoperable with it”.

It is only by taking a decision to start the full implementation Phase that Europe will have the final benefit of the current involvement of industry throughout all European countries.

Involvement of industry in the detailed design of the system user's oriented demonstrations, will lead progressively to integration of GALILEO in users terminal, development of innovative applications involving SMEs, synergy between Navigation Communications and other functions commercialised by service providers. It is a similar mechanism largely supported by public funds, that has led to enormous commercial revenues in the US and the same will happen in Europe when GALILEO is fully implemented.

GALILEO benefits

The fact of simultaneously drafting a regulation policy while GALILEO is still under design puts Europe in a unique position: the design of the system can take into account the objectives of the policy and vice versa. The policy will build upon the unique features of GALILEO in particular its capacity to offer robust signals allowing users to be alerted in case of interruption of the system and its resistance to interference; these improved performances moreover guarantee the users and will

allow an increase of the number of applications and as a consequence increase the involvement of European Industry.

The implementation of GALILEO will allow Europe to fully participate in the development of international standards.

The capacity of European member states to steer GALILEO definition would allow to offer guarantee of a certain levels of performances and also to make it interoperable with some others ground and/or based space systems in particular GPS. Interoperability with GPS would allow users to benefit from better performances than the ones from each individual system: this means as well that current users of GPS would benefit from the implementation of GALILEO by correctly retrofitting their terminals.

Urgency of the decision

It has also to be stressed that to take full advantage of the benefits described the implementation of GALILEO must be properly scheduled. The target to have an operational system in 2008 is consistent with the schedule of deployment of GPS III, new generation of spacecraft. This target is necessary to take a share of the market in appropriate time. Incompressible delays for mandatory technical and operational steps such as in orbit validation of the system, full experimentations, development of ground and space elements,... lead to the obligation of taking a decision to go ahead as soon as possible.

The on-going industrial activity gives the grounds to design GALILEO adequately to the objectives described. Moreover to correctly design the interoperability with GPS and to translate security policy guidelines require the setting up of working relationship with the DOD GPS project office and active participation in international standardisation groups.

All activities related to frequencies are also time sensitive. At the World Radio Conference in Istanbul in May 2000, Europe through all its member states had the capacity to obtain from the International Telecommunications Union appropriate allocation of the radio frequency spectrum. Such an allocation is only provisional and, at the International Conference in 2003 in Caracas, it is of paramount importance to secure the spectrum. Preparatory work towards this conference is going on. Meetings at regional level are scheduled in the short range. It is clear that to correctly promote the GALILEO objectives in this area a go-ahead to GALILEO is needed.

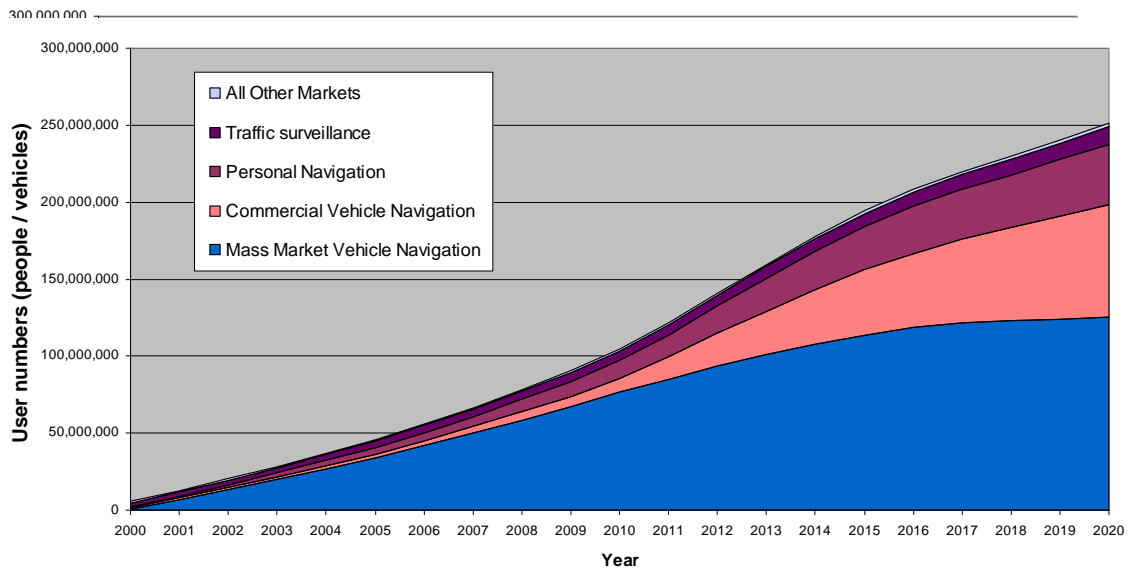
ANNEXES:

- 1-** Current and future use of GNSS by mass markets
- 2-** Vulnerability of GPS: Impact of the VOLPE report on GALILEO and the GNSS-2
- 3-** Galileo differentiators and combined GPS-GALILEO services.

ANNEX 1: Current and future use of GNSS by mass markets

In the early years of the GPS programme, civil use of GNSS was mainly restricted to professional purposes such as surveying and scientific research, but that situation is rapidly changing as the use of satellite navigation is becoming more widespread across many different market sectors. The use of GPS is rapidly moving into the mass consumer markets starting with sports and leisure activities such as yachting, hiking, etc., and continuing with more and more cars being sold with in-car navigation systems with integrated GPS. The first true mass market multi-functional devices (GPS/GSM or GPS/PDA⁹) have recently become available in the market. In 2000, there were approximately 6 million civilian GNSS receivers in use in Europe, however this market is expected to grow rapidly over the coming years and it is estimated that there will be around 100 million receivers in use in Europe in 2010, increasing to 250 million by 2020. This is shown in Figure 1 below which illustrates the growth in the four top markets¹⁰.

The largest growth in this market is likely to come from the personal use of GNSS, in vehicles and possibly in mobile phones. The sales of location based information services are expected to grow dramatically as the next generations of GSM technology¹¹ are rolled-out over the next few years, allowing larger volumes of data to be transferred to mobile platforms. If GNSS is the chosen positioning technology for such infomobility services, the number of GNSS users will dramatically increase, as new mobile phones will have integrated GNSS technology. Regulation concerning the automatic location pinpointing of mobile phone users making emergency calls, will also drive this market.



⁹ Personal Digital Assistant

¹⁰ Market Research Methods and Overall Results, GALA DD005, February 2001

¹¹ Like GPRS or UTMS

Figure 1: European GNSS Market Size

It can be seen from the market forecast figures above that personal navigation and in-car navigation will be the largest markets in terms of user numbers, exceeding by far the next two largest markets, that of commercial vehicles and traffic surveillance. It is estimated that over the next 20 years, 70-80% of all GNSS receivers sold in Europe will be for personal use. Thus it is clear that, in the absence of GALILEO, increasing numbers of European citizens will become dependent on GPS. On the assumption that there will be convergence between in-car and personal navigation equipment by 2020, it can be predicted that over 65% of the population in Europe will rely on GNSS while going about their business and daily lives.

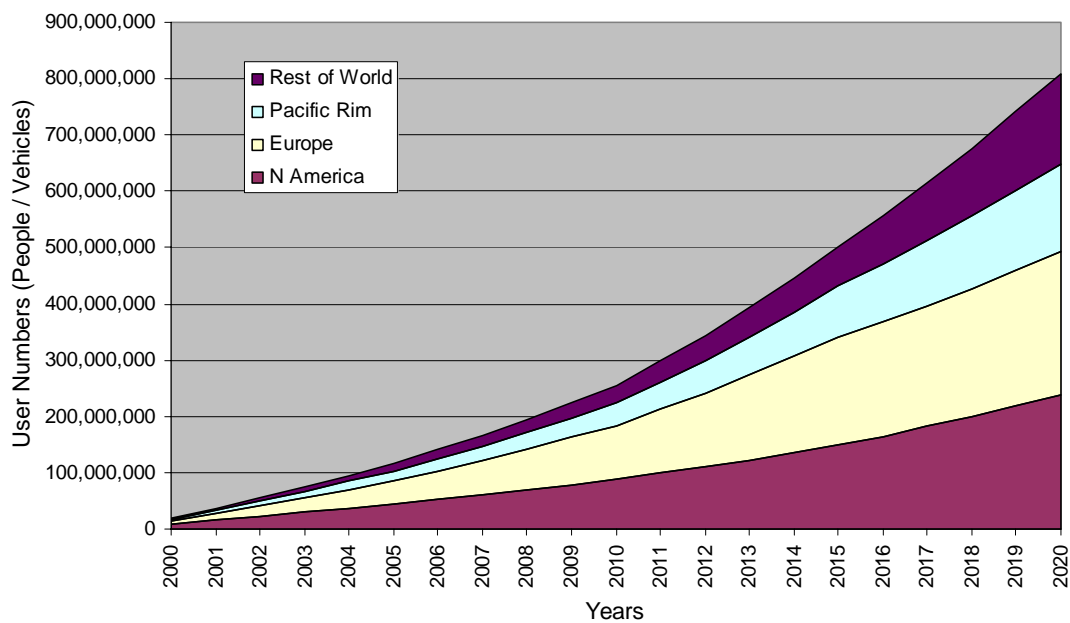


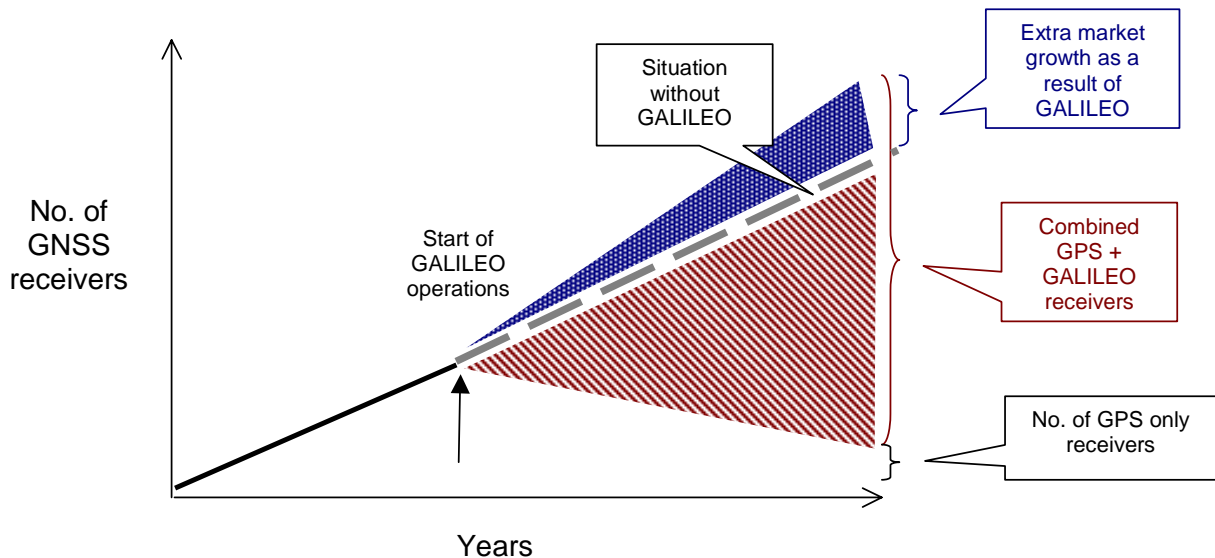
Figure 2: Global GNSS Market size

It can be seen from Figure 2 that the global market for GNSS is predicted to grow to 800 million users by 2020. The European market is initially smaller than the North American market but will grow to a similar size by 2020, representing about 30% of the total market for GNSS.

If GALILEO is launched as a second independent satellite navigation system, the market uptake of GNSS is likely to grow even faster and further than forecast above. The combined use of GPS and GALILEO will offer users a huge availability advantage especially in urban areas¹². As a consequence, the current thinking is that the vast majority of future GNSS receivers will be combined GPS and GALILEO receivers. The large benefits gained by combined use of both systems will easily outweigh the small cost disadvantage expected in producing combined receivers. This trend in the future use of GNSS is illustrated schematically below where the number of GPS-only receivers is foreseen to decrease in

¹² an increase of availability from 55% to 95% in urban environments (GALA WP 7 analysis)

favour of the combined receivers. In this respect, the latest market analysis study¹³ is no longer considering GALILEO and GPS as competitive systems, but rather as complementary ones.



Thus, the total benefit from GALILEO will increase through two mechanisms. First, through an increase in the total number of people using GNSS, and second through a marginal increase in the benefit per user as a result of the improved service offered by the two systems. These benefits will be maximised if GALILEO is independent from, but interoperable with GPS.

This will be true for mass market applications of GNSS which are concentrated in urban areas, but many other market sectors will also gain from having a second GNSS system in GALILEO. This is especially true for the safety-critical market sectors such as civil aviation and maritime, where reliance on a single navigation system is not acceptable. These sectors currently use GPS but still rely on expensive ground infrastructure to supply independent positioning information and/or integrity augmentation for GPS. For any single sector, the space-based solution offered by GALILEO for navigation would seem to be expensive as compared to their 'individual' ground based solutions (e.g. at airports or in harbours) and hence no single industry is willing underwrite the full costs. However, the key issue is that, by its very nature, a satellite-based solution will support many different applications at the same time, thus making it a cost-effective overarching solution for amongst others, aviation, marine navigation, road charging and automatic driver assistance systems (ADAS) for cars.

Economic activity due to GNSS

The global revenues arising from the sale of GNSS products is shown in Figure 3. These gross revenue or industry turnover figures were derived from the number of receivers multiplied by the full price of the GNSS terminal product offered on the market and bought by the end user

¹³ The GALILEO Market Observatory study commissioned by the EC, as part of GALILEI.

(i.e. the entire car navigation system, mobile phone, surveying system or stand-alone receiver). This represents the total revenues that will accrue to all the industry players across the entire value chain, including the signal provider, the component (chip and antenna) manufacturers, equipment producers and system integrators.

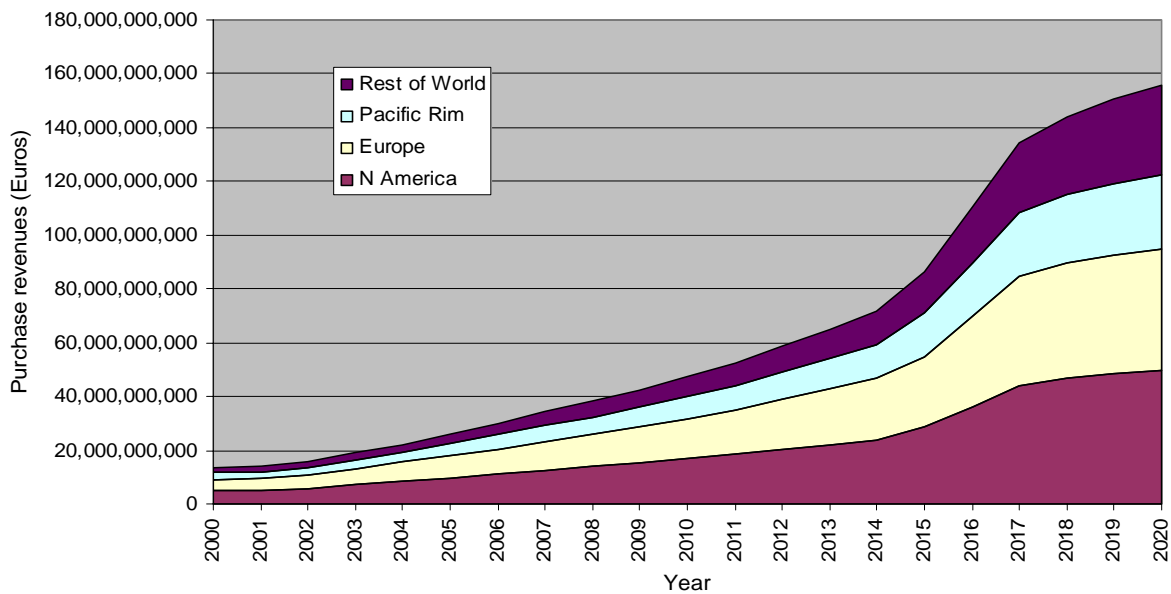


Figure 3: Global revenues from GNSS enabled products

The global revenues from GNSS product sales is predicted to grow rapidly from around 14 billion € in 2000 to 50 billion € in 2010 and to 155 billion € in 2020. The total revenues start flattening out after 2017 as the market for GNSS receivers starts becoming saturated.

What proportion of these revenues accrue to European suppliers versus US suppliers has not been assessed. However a study on the competitiveness of the European satellite navigation industry carried out in 2000¹⁴, brought to light some interesting results. They found that Europe had few suppliers of GPS chipsets / receivers for high-end applications as well as low-end mass market products, resulting in a technological dependence on US technology providers. On the other hand, Europe's industry was moderately successful in the system integration sector, and was strong in the service provision domains of ATM (air traffic management) and fleet management. They also found that Europe had taken the technological lead in the service provision for car navigation (telematic services) and mobile phones.

¹⁴ Structural Analysis of the European Satellite Application Segment, Final report October 2000, Technomar GmbH

It is likely that the industry turnover will be even larger if GALILEO is launched. Unlike GPS, GALILEO will offer certified and/or guaranteed services for which the user will be charged. This will in turn lead to revenue streams from service provision in addition to the revenues from product sales. It is thought that the revenues from services will match or even exceed those from products by 2020¹⁵.

Notes on Timing Dependency

Accurate time referencing is fundamentally important to the performance of digital networks that use high-speed data transmission systems, such as those used by fixed telecommunications, mobile phones, mobile radio and digital broadcasting. Timing slips (between receive and transmit clocks) result in repetition or deletion of data, which in turn can lead to loss of service quality for voice, fax or video transmissions or will require re-transmission of data or key codes.

GPS timing is mostly used in conjunction with free running atomic (caesium or rubidium) clock technology, since the lack of robustness of the GPS signal was recognised from the start (mainly due to simple radio interference or masking). A synchronisation network is typically based on the deployment of a small number of caesium sources together with GPS since this is the most resilient solution. The caesium clocks form the expensive primary reference source and the GPS the cheaper slaved source. However, GPS time, since it is referenced to the Mater Clock at the US Naval Observatory, is used to synchronise the atomic clocks that can drift.

The consequence is that a short-term outage (hours) of GPS signal will have no adverse effect, but if it continues for a longer period of time, the drift in the master clocks may start causing disruptions to the networks. If the outage continues, the service quality could deteriorate and eventually fail.

¹⁵ Market Research Methods and Overall Results, GALA DD005, February 2001

ANNEX 2: IMPACT OF THE VOLPE REPORT ON GALILEO AND GNSS-2

1 Introduction

On the 22nd May 1998, The White House issued a Presidential Decision Directive (PDD-63), which instructed the US Department of Transport to '*undertake a through evaluation of the vulnerability of the national transportation infrastructure that relies on GPS*'. This report entitled 'VULNERABILITY ASSESSMENT OF THE TRANSPORTATION INFRASTRUCTURE RELYING ON THE GLOBAL POSITIONING SYSTEM' was prepared by the John A. Volpe National Transportation Systems Centre and delivered to the US Department of Transport on the 29th August 2001. It was made generally available as an unclassified document the following month and has become more commonly known since then as 'THE VOLPE REPORT'

Whilst this report dealt specifically with the issue of GPS usage within the transport infrastructure of the US, its findings are still pertinent for both the proposed Galileo system and Europe. What follows is a summary of the main findings and recommendations of The Volpe Report. The influence that both Galileo and combined GPS/Galileo, more commonly referred to as 2nd Generation Global Navigation Satellite System (GNSS-2) will have on The Volpe Report, are then addressed. Finally some general conclusions are drawn.

2 Main Findings of The Volpe Report

What follows is a distilled version extracting the key points of the full 7 page Executive Summary that appears at the beginning of The Volpe Report. This Executive Summary highlighted 3 key areas, which are in turn briefly discussed below.

2.1 Overarching Issues Related to GPS Vulnerability

- There is growing awareness within the transportation community of the risks due to interference associated with the GPS system being the only means for position determination and precision timing.
- The vulnerability of GPS to interference can be reduced but not eliminated.
- The most serious consequences of any impairments to GPS are very likely to occur and can be avoided by awareness, planning and supplementing GPS with a backup system or operational procedure when used in critical applications.
- The potential for inducing a GPS receiver to produce misleading information exists

As a result of these findings the following recommendation was made:

- Public policy must ensure that safety is maintained even in the event of loss of GPS but this may not necessarily require a backup navigation system (primarily due to costs) for every application. Of secondary but immediate

importance is the need to minimise adverse environmental or economic impacts.

2.2 Mitigating the Vulnerability of the GPS Signal to Disruption or Loss

- The GPS service is susceptible to unintentional disruption from a number of sources and these disruptions are most noticeable for users of single frequency receivers.
- The GPS service is also susceptible to intentional disruption. This could take the form of jamming at one extreme to actual physical destruction of the infrastructure of GPS its-self.

These findings resulted in the following recommendations:

- The on-going GPS modernisation programs involving higher GPS broadcast signal power and eventual availability of 3 civil frequencies should be encouraged.
- GPS receivers involved in critical maritime and surface applications should be certified by the appropriate regulatory authority.
- Systems and procedures to monitor, report, and locate unintentional interference should be implemented in any application for loss of GPS is not tolerable.
- Continuing assessments of the applicability of military anti-jam technologies to the civil sector should be made.

2.3 Mitigating the Vulnerability of the Transportation System to the Loss or Degradation of the GPS Signal

- The GPS system cannot serve a sole source of position location or precision timing for certain critical applications.
- Backups for positioning and precision timing are necessary for all GPS applications involving the potential for life-threatening situations or major economical or environmental impacts.

These findings resulted in the following recommendations:

- Create awareness amongst members of the domestic and global transportation community of the need for GPS backup systems or operational procedures.
- Encourage all transport modes to give attention to autonomous integrity monitoring of GPS signals (RAIM).
- Conduct a comprehensive analysis of potential backup systems to GPS across the various applications.

2.4 Summary

It can be concluded from these findings and recommendations that, whilst The Volpe Report underlines the potential for GPS to become a key infrastructural element, it also stresses that GPS cannot act as a sole means systems where the effects of its loss or marked performance degradation, for whatever reason, could lead to either loss of life or major economic or environmental damage.

3 Influence of Galileo and GNSS-2 on the Findings of The Volpe Report

As highlighted in Section 1 of this document, the remit of The Volpe Report was to examine the utilisation of GPS in the US transport infrastructure. However as Galileo is designed to be, like GPS, a satellite based radio navigation system providing continuous global coverage, the subject areas discussed remain equally valid for both Galileo and GNSS-2. The 3 key areas documented in Section 2 are thus now re-examined considering these systems.

3.1 Overarching Issues Related to Satellite Vulnerability

Galileo will have some important differentiators between its-self and GPS in the Volpe domain, such as multiple civil frequencies, integrity and encryption of civil frequencies, which mitigate the shortcomings of GPS characteristics in terms of interference, performance monitoring and resistance to production of misleading information. As the potential effect of each of these characteristics is environment and application specific, so to is the potential for the level of mitigation.

When the GNSS-2 solution is considered the situation is further improved as inherent single system weaknesses such as Single Point Failure and reduced performance due to limited availability in some environments are also reduced.

3.2 Mitigating the Vulnerability of the Satellite Signal to Disruption or Loss

GPS, Galileo, and thus GNSS-2 signals are all inherently vulnerable to interference at user level due to the very low received signal power. However where Galileo offers an advantage over GPS is the increased bandwidth over which its signals will be broadcast. This makes it less likely to be interfered with accidentally, and much more difficult to be interfered with intentionally. This situation is further improved in the case of GNSS-2 as the bandwidth on which signals are broadcast is still further increased.

The inclusion of an integrity service within Galileo enables the end user to associate a confidence with the position derived using the broadcast SISA figure and to discard observations exceeding this limit through use of the Integrity Flag. This presents advantages over Receiver Autonomous Integrity Monitoring (RAIM) which is the system used by GPS as it does not require that 6 satellite signals be simultaneously received to detect a single outlier, but also offers quantifiable performance measurements for each signal which result in the ability to provide service guarantees.

Encryption of Public Regulated Service (PRS) within Galileo makes it much more difficult for malicious groups to fool users of this system into using false information (Meconing) than it is with unencrypted civilian GPS signals.

3.3 Mitigating the Vulnerability of the Transportation System to the Loss or Degradation of the Satellite Signal

When considered on its own Galileo is, like GPS, an autonomous and independent system, and thus the conclusion that a single system cannot serve as a sole means system for certain critical applications, remain equally valid for Galileo.

This is not the case for GNSS-2 however as the independence of the individual systems becomes a major strength. In the event of GPS failure, there should remain Galileo and vice-a-versa. Indeed the situation is in fact better than that, as the interoperability of the systems means that when operating in highly demanding environments such as Urban Canyons which restrict satellite visibility, the combined performance will provide significant enhancements over the individual performances of either GPS or Galileo, opening up applications that would otherwise be impossible for either GPS or Galileo to fulfil alone.

As both systems are designed to be available globally and share a great many characteristics it is also true that combining the systems is easier and more cost efficient than for alternatives such as GPS or Galileo / INS integration.

4 Conclusions

The Volpe report has served as a timely reminder to those who would over estimate the potential for GPS to meet the performance requirements in the field of civil transportation. Problems related to interference, integrity monitoring, meconing and system failure have all lead to the raising of serious concerns as to the potential for its performance both now and in the future.

It can be seen that in terms of the first three of these limitations at least, that Galileo offers improved performance over GPS. The fact that the system has been designed from a civilian perspective has lead to it having the potential to broadcast encrypted signals to civilian users over a number of frequencies, with associated integrity information, thus mitigating the potential effects of such feared events.

What Galileo and GPS cannot do is escape the fact that they are both single independent systems, and thus for certain critical applications will never be acceptable for sole means of use as they remain vulnerable to system failure. However the very fact that they are independent but interoperable means that by combining them the need in such applications for a backup system can be met whilst not only maintaining the advantages in terms of cost and global coverage that make them so attractive in the first place, but improving performance characteristics in a great many instances.

ANNEX 3: GALILEO DIFFERENTIATORS AND COMBINED GPS/GALILEO SERVICES

1. GALILEO UNIQUE FEATURES

The fundamental designs of GPS and Galileo are very similar – which is not surprising since they fulfil the same basic functions. GPS is a mature system that is already undergoing its third and planning its fourth update cycles. GPS is therefore approaching the physical limits of position and velocity accuracy achievable with the given frequency bands and technologies. There are four main differentiators for Galileo: service guarantee, global integrity monitoring, improved service performance and signal, and search and rescue services.

1.1 Service Guarantee

The service guarantee concerns the complete service over a given period, that is to be defined and may depend on the service and on the users. In particular, safety-of-life services and commercial services will be provided with a service guarantee. Technically, this service guarantee is provided firstly 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 guarantee will directly impact the required reliability of the system as well as the replacement strategy.

From a legal point of view, the notion of service guarantee 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 may 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, who will assume responsibility for abnormal events. This implies to set up a precise institutional and organisational framework with defined roles, responsibilities and liabilities,
- A compensation mechanism to reimburse damages,
- A jurisdiction/recourse mechanism.

1.2. Global Integrity

Galileo will provide a set of services (in particular the Safety-of-Life Service) that includes the provision of integrity information concerning Galileo satellites. This information, which could be encrypted (for instance for authentication purposes), 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.

The Galileo integrity information will be provided to the users through the following data:

- Signal In Space Accuracy (SISA): the uncertainty estimates of the Galileo ranges transmitted by Galileo are called Signal In Space Accuracy (SISA)
- Integrity flags for demanding operations, which warn users 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). For a given satellite, the Integrity Flag (IF) allows to determine whether SISA is OK (in this case the satellite can be used), or the satellite is not monitored, or SISA is not OK :(then the satellite is not to be used).

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

- A satellite was functioning and is no longer doing so,
- A satellite was functioning and is no longer monitored.

When such a case occurs, an immediate alarm is sent to the users through the Galileo signals.

1.3. Improved service performance and signal

These improvements are due to various factors:

- Higher data rates than GPS will allow integrity, SAR and limited commercial data
- Wider bandwidth E5A+E5B versus L5 gives better accuracy
- Slightly higher signal strength may improve operations indoors
- Greatly superior ionospheric modeling techniques provides higher accuracy for the single frequency user, although GPS will catch up on this undoubtedly
- Galileo will transmit on at least three ITU-sanctioned frequencies (GPS will use two such frequencies plus a third unprotected military frequency)
- The introduction of authentication mechanisms (asymmetric crypto transparent to user) is considered to protect the user and the operator in a service guarantee environment.

1.4 Search and rescue services

Galileo will improve the time-to-detection and the accuracy of location of distress beacons by extending the current COSPAS-SARSAT Search and Rescue mission and provide an acknowledgement to the user that the distress message has been received.

Galileo will ensure compatibility with COSPAS-SARSAT beacons. The payload embarked on Galileo satellites 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.

It will also improve the 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 Search and Rescue 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 Search and Rescue-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.

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

2. ENHANCEMENTS RESULTING FROM COMBINED USE OF GPS AND GALILEO

Society is becoming evermore dependent upon GNSS signals in their daily lives, often without knowing it. The growth in use of GNSS systems, most visible today in the automobile market, and soon in the nascent portable telephone/GNSS market, dictates that in positioning also we will grow steadily more dependent upon a robust GNSS service. If this is really the case, then there must be a high degree of confidence that the service will not be interrupted, though the average user will have no interest whether the satellites are GPS, Galileo or any other system, as long as it meets their requirements. The traditional solution for provision of such confidence is to provide redundant systems. GNSS is no different in this respect.

Europe must therefore meet the requirements of its citizens with robust GNSS services, and a GNSS system that provides their needs must be available with a very high degree of confidence. A borrowed GPS signal from another nation is hardly a recipe for the underpinning of Europe's inevitable dependence upon such signals. Provision of a redundant system to GPS will give the public the necessary confidence

to build businesses, capabilities and services on the foundation of reliability provided by such redundancy.

2.1 Performance improvements

In an open space environment with no sky obstructions, either constellation would allow 6+ satellites to be visible. This gives sufficient redundancy for mass-market non-safety applications. With a single constellation the autonomous receiver integrity computation capability is marginal and is not trusted for safety of life applications. Two interoperable constellations will allow the receiver to compute two non-dependent robust solutions, but when (political) conditions allow, the receivers would be free to regard the 24 GPS satellites and the 30 Galileo satellites as a single GNSS constellation. Mathematically, the positioning solution will be massively over-determined and the ability for receiver self-checking (integrity) for rogue satellites will be much more robust. Galileo will still need an autonomous integrity capability for those, hopefully, rare occurrence where the GPS system cannot be used, but joint integrity potential could provide an extremely high degree of confidence to the user.

Higher availability in the cluttered view environment will allow a more robust positioning capability purely as a result of the greater probability of having a clear view to sufficient satellites for a robust positioning solution.

2.2 Safety Critical Services

If Safety Critical Services are to use GNSS systems as their time or position providers, then the GNSS system must clearly meet safety critical levels of service with respect to accuracy, availability, continuity and integrity. It is unlikely that GNSS will ever reach its full safety critical potential with a single GNSS system. Provision of a second system will allow a greater penetration into the realm of safety critical services. This area is fraught with difficulty, and safety critical services must be developed very cautiously over a lengthy time frame to allow the necessary confidence to be built.