Planning of Future Satellite Navigation Systems

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This paper is based on the results of the 'GNSS Support Task' study for the European Commission, DGXIII. It summarises the results of the cost benefit analysis in terms of coverage, accuracy and safety requirements for different types of user and describes the most cost-effective GNSS 2 architecture. These analyses also assume that the overall system is layered into wide area, regional and local systems. The future planning of satellite navigation is essentially driven by the wide area requirements and ensuring that these are global and seamless. There is some flexibility in coverage and accuracy for a wide area system in that it can be augmented regionally or locally if required, but it must provide the highest level of safety required. The paper approaches the architecture for a future navigation system from this safety aspect. An analysis of the chosen architecture shows that the required safety performance can be met. An implementation plan is described which allows a gradual evolution from the first system to be realized for safety critical operations to a fully civilian owned and operated system.

1. introduction. Satellite-based services have been universally welcomed by a variety of users amid high expectations of significant economic and other benefits, but it should not be assumed there is a blank cheque for all future satellite-related developments. It will have to be demonstrated that any successor to GPS and GLONASS provides worthwhile benefits. Studies[1,2] have shown that the early benefits from GNSS are dependent upon achieved performance, geographic location, the available alternatives, and the user application. As an example in aviation, in the core area of Europe the principal benefits are expected to be economic, but elsewhere the benefits should be more substantial through opening up of more air routes and thereby making more efficient use of the airspace. Approach and landing applications seem likely to be beyond the capability of GNSS 1 but must be supported by GNSS 2; however, this should not be at the expense of those users who have less need for such safety critical support.

GNSS 2 will have to satisfy many user applications, each requiring a different level of safety and accuracy performance. It will have to be commercially attractive. It will be difficult to complete the transition to a new system in a cost-effective and timely manner when so many users will already be equipped with versions of GNSS 1. Undoubtedly there will be institutional, political and funding hurdles to overcome, but the assurance and long-term security offered by an internationally-owned civil system would seem to make it worthwhile. It is against the background of diverse applications as well as some constraints that the planning must take place for a future GNSS 2. This poses a significant challenge for system planners and designers. Our paper discusses some key factors likely to influence GNSS 2 design particularly in respect of safety, effectiveness and application, and offers a suggested approach for the design optimisation of GNSS 2 and its evolution from GNSS 1.

2. design drivers.

2.1. *Need Drivers.* Europe should ensure that the development of GNSS 2 is need-driven and avoid the risk of a technology-driven development that nobody wants and which will almost inevitably be expensive. There is never any shortage of new and exciting technologies and the enthusiasts can dream up a vast array of user applications that can be satisfied by the latest technology. Questions like: 'Is it a sensible application for this technology?', 'Does the user want it?', 'Is it the best solution?', 'What are the costs and benefits like?', are often ignored until the time the user is asked to pay for it. Only then do you find that the user didn't want it as much as was thought.

At first, it appeared GNSS might be different because the free satellite navigation service offered by the US Department of Defense GPS standard positioning service enabled users to take immediate advantage of the technology. They only had to consider the cost of buying and integrating receivers against the operational and financial benefits to be gained. For some users, the benefits were immediate. Low-priced GPS receivers quickly became available to everyone, and even safety-related uses such as aeronautical navigation were able to apply the technology to a limited extent where other navigation facilities were not available. However, it became apparent that there were shortcomings in safety performance, and concerns were expressed over the long-term risks to availability from the monopoly suppliers of GPS (and its sister technology GLONASS). Some of the attractions were short-lived due in part to the need to improve safety features such as availability, integrity and service continuity. In the event, these safety concerns whetted appetites and led to the development of a plethora of augmentation techniques and systems and the inevitable consequence of a technology take-over. Some users are becoming nervous and even critical of projects to enhance GNSS performance, and it will be important to encourage their active participation in the development of GNSS 2.

Now there is the prospect of an internationally-controlled, civil GNSS – for some, this is a driver in itself – and it can reasonably be assumed that system developers will wish to exploit the technological developments and offer additional capabilities for which the users will be expected to pay. The lesson learned by aviation from the miscarriages of the ill-fated ICAO development of a new landing guidance system, the Microwave Landing System (MLS), is that system developers must work closely with the users, and must not get carried away with the technology.

There must be a clearly defined set of user requirements, and the system solutions proposed by the engineers must be tailored to those needs and not to some more esoteric application that seems nice to have. The system costs versus the financial benefits must be positive within a reasonable time period. In addition, it should be assumed that where a 'multi-modal' system is being proposed for many different applications and user communities, that each user is only asked to pay for the functions and performance levels appropriate to his application. The proposed system features and performance levels must be clearly mapped to each user

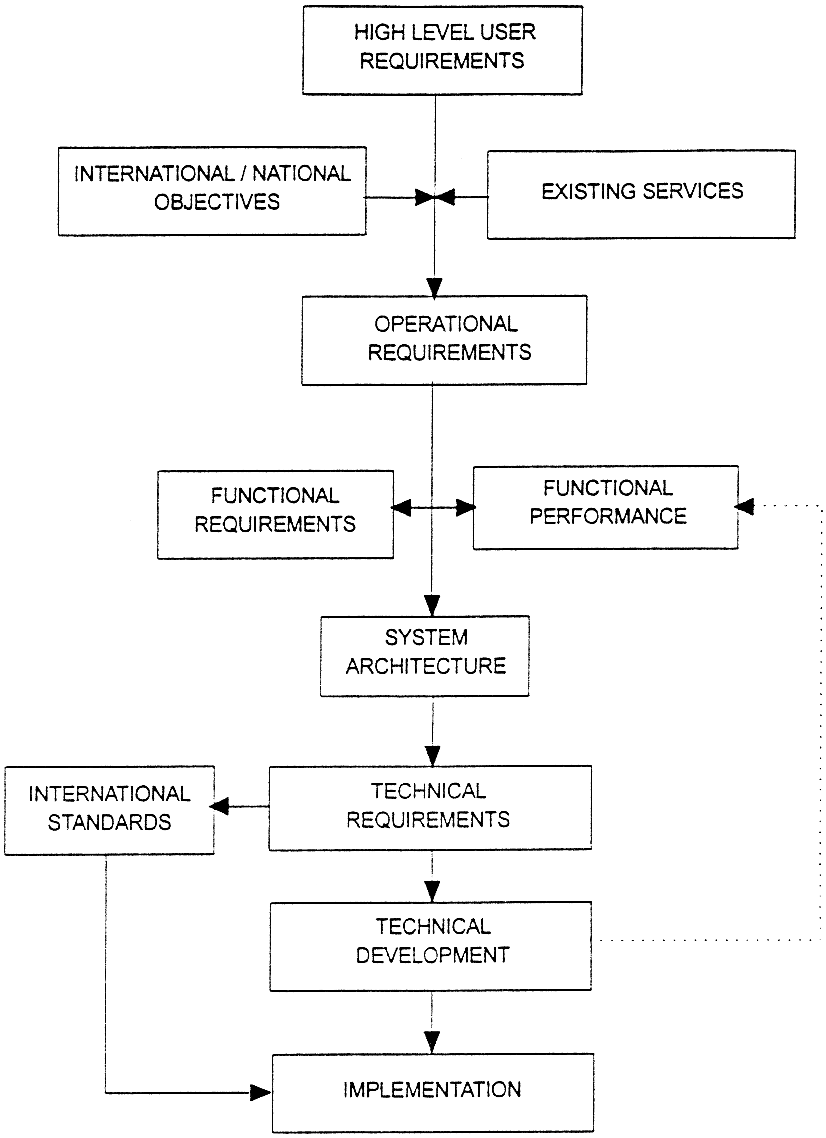

Figure 1. System development strategy.

application, and a cost–benefit study conducted to determine that each system facet or performance level is justifiable and affordable.

Figure 1 illustrates what is perhaps an idealised approach to system development but which, in principle at least, sets out a 'road map' for GNSS 2.

2.2. *User Requirements*. Studies conducted for the European Commission[2] have addressed the first step by identifying a possible range of user applications and a summary of these is shown in Table 1. This list draws heavily on the European Radio Navigation Plan.[3] It must not be assumed to be a list of possible applications representing user requirements. The latter can only be defined by the user, and that

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Table 1. User applications summary

	Essential		
	Safety of life	Other	Non-essential
Global	Aviation: RNP 20, 12, 10 Marine: Oceanic phase Marine: SAR	Timing and frequency Space Fisheries – deep sea Meteorological	Recreational Animal tracking
Regional	Aviation: RNP 4, 1, NPA Marine: Coastal phase Road: Safety and security Road: Collision avoidance Rail: Train location and control	Rail: Management information Road: Fleet management Meteorology Hydrography Fisheries & enforcement Land survey Marine survey	Road: Information services Road: Navigation Road: Demand management Rail: Passenger information Agriculture and forestry Animal tracking
Local	Aviation: Cat I, II and III, SMGCS Marine: Harbours Inland waterways Rail: Train location and control	Marine: Dredging Marine: Hydrography Tracking personnel and containers	Road: Traffic control Agriculture and forestry

is why it will be important to involve all users in the GNSS 2 planning and development process.

It can be seen that applications have been grouped in two ways. First, three categories have been chosen according to their safety criticality; (i) Essential use – safety of life, (ii) Essential use – other applications, and (iii) Non-essential use. Second, in terms of the proposed application coverage for which three other categories have been chosen; Global; Regional; and Local.[1,2] It is recognized that the categorisations are somewhat subjectively based on current capabilities and may change, particularly if dependence on GNSS 1 increases, then applications may move from Non-essential to Essential. Also the distinction between local and regional is not always a clear dividing line.

The question to be resolved is whether or not one single system can satisfy all user applications in such a manner that each system facet and performance level is justifiable and affordable to all users. If not, then it would be better to differentiate between users and their needs and develop a GNSS 2 architecture that can be configured to suit each application.

It can be envisaged that for GNSS there are a number of evolutionary stages – the transition from the existing navigational aids to satellite technology, the transition from GPS/GLONASS to augmented systems such as EGNOS, and the transition from GNSS 1 to GNSS 2. Each stage must be justifiable in terms of the additional cost versus the incremental benefit.

2.3. *Safety Requirements*. Safety and the assurance of the future availability of a satellite navigation service that is designed for the purpose are persuasive arguments for planning a replacement system, particularly if it is under civil, international

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control. Neither GPS nor GLONASS were designed for safety-of-life applications, and most of the measures to augment these systems are designed to overcome a shortcoming in safety performance but are expensive accoutrements to the baseline global navigation service. In establishing policy, and the acceptability of a target level of safety, public perception of safety plays an important part and whilst 'absolute safety' may be sought, the public would not accept the high cost of such even if it were achievable. Hence a practical and achievable balance is necessary.

In developing GNSS 2, safety requirements must be mapped on to the user application. The term Required Navigation Performance (RNP) used in civil aviation has been adopted as a means of identifying performance requirements. These requirements are essentially accuracy, integrity and continuity of service. Another RNP parameter is availability, which does not normally have a direct safety implication but can have a significant economic impact and, for some users, may dictate the need for an alternative system as back-up.

Analysis of the full list of RNP parameters shows that integrity, continuity and availability usually 'track' each other, and that when consolidated, they can be used to define safety criticality. Safety criticality can be used to determine the level of redundancy and integrity monitoring required by the candidate architecture. Accuracy and coverage can also be associated in that very high accuracy is generally required over relatively small areas. Accuracy may also be coupled with the need for real-time positioning, update rate or time-to-fix.

These considerations have been the catalyst for the development of augmentation systems such as EGNOS which improve safety and reliability to the level needed to support safety-critical applications. The need to demonstrate high integrity has led to the development of dependent techniques such as Receiver Autonomous Integrity Monitoring (RAIM) and independent integrity monitoring functions such as Ground Integrity Monitoring (GIM). Stringent safety requirements may also lead to the inclusion of design features such as the diversified development of software and hardware to minimize the risk of common failure modes. The need for these design features would become evident from system reliability and operational hazard analyses which are an important step in determining the design of any safety system used for public transport purposes.

2.4. *Coverage*. It is sensible to take advantage of the global nature of satellite technology where possible, but not if that places undue technical performance and cost demands on the system in order to satisfy special requirements or more localized applications. Many applications are of a global nature and do not require extremely high accuracy; often the available accuracy from GPS or GLONASS is adequate and GNSS 2 may not need to be better. Later in the paper, it is proposed that the baseline performance of GNSS 2 should equate to that achieved with a GPS/GLONASS combination. On the other hand, safety or commercial considerations can demand higher levels of performance from the service which would require further enhancements. All the currently proposed wide area systems are planning to incorporate geo-stationary satellites to broadcast differential corrections and integrity data, and to transmit ranging signals to provide additional ranging sources over-and-above GPS and GLONASS.

Table 1 showed that applications could be grouped in coverage terms, and in fact there can sometimes be an inverse relationship between coverage and accuracy. As the highest accuracy (and often the highest reliability) requires the use of augmentation techniques, this suggests the concept of a multi-layer approach to the GNSS 2 architecture, where the more demanding performance enhancements are designed to serve regional or local areas and are only available to those who need them.

All systems would derive basic navigation information from the baseline satellite service. The upper layer might not require performance enhancement external to the GNSS receiver, i.e. be autonomous, but lower levels would probably require the support of a ground-derived augmentation service and a monitoring facility which would uplink very accurate correction data to the user rather than depend upon a receiver and its associated reference.

2.5. *International Standards*. A system designed for safety applications should take full account of the relevant standards now emerging for safety critical systems such as IEC 1508[5] (in draft at present) and other relevant national or international technical and operational performance specifications. Compliance with such standards may be affordable for safety-of-life operations but can impose a high – yet probably unavoidable – price on non-essential applications. This is an inevitable consequence if one system is designed for a wide variety of user applications and yet perhaps only a small proportion of these need to undergo some form of safety assessment or formal approval process.

At present, only international civil aviation (ICAO) has attempted to develop technical specifications for satellite navigation systems, adopting the publicized technical characteristics for GPS and GLONASS and developing its own GNSS performance standards. In the case of GNSS 2, it can be expected that international organizations like ICAO and IMO will need to be consulted and probably be involved in the development of system technical characteristics and performance specifications. It is noted that there is no similar international organization representing land mobile or other users; however, in Europe, their interests will perhaps be covered by the EU. Certainly if GNSS 2 is to be used in aviation, internationally recognized and approved technical standards will need to be developed and applied in the system design.

2.6. *Costs*. Cost is clearly a design driver and, for GNSS 2, the main driver will be the capital outlay for the space segment, which will probably be the major proportion of the total initial cost. These days, the general rule assumed in cost–benefit analyses is that the costs of developing and operating the system should be recovered from the users in the form of a charge for using the service. Measures such as licence fees or receiver royalties may be considered; the added complexity of encryption techniques may be needed to prevent unauthorized access and so on.

The cost–benefit analysis reported in the EU GNSS Support Task[2] suggested that government funding would be necessary at least to cover the non-recurring cost associated with the initial implementation of the baseline system, and that somehow this cost would be recovered from the users over a period of time. It was assumed the development cost of system enhancement would be funded in a similar manner.

It has to be recognized that the present attraction of satellite technology stems almost exclusively from the fact that GPS and GLONASS were funded by two governments out of general taxation – for military reasons – and both systems were then made freely available to everyone – for political reasons. It must also be remembered that significant expense will have been incurred in the setting up of the augmentation service for GNSS 1. GNSS 2 should make as much use as possible of this investment. This is particularly true in Europe with EGNOS, where this development is under civil control and provides not only a technical stepping stone but an institutional one as well.

Whilst it may not be fashionable these days, it would resolve many problems if governments could agree to a similar course of action and fund the development and operating cost of a baseline GNSS 2 out of general taxation. This is seen as the only means of giving an incentive to transition to GNSS 2, overcoming the problems of cost recovery which would be almost impossible to regulate and administer across the whole user-population and avoiding increased system cost and complexity for encryption. The baseline architecture would be chosen to be the simplest, lowest-cost option to be effective and consistent with the minimum performance requirements deemed necessary for a global system. The development and operating costs associated with all equipment needed to deliver performance enhancements for regional and local services would be recovered in full from those users who benefit from these services. It might mean that such services will need means to control access.

2.7. *Backwards Interoperability*. One issue to be resolved is the extent to which GNSS 2 should be interoperable with GNSS 1, if at all. Since GPS is already freely available and in widespread use, it might be self-evident that this could be taken as a core element of any architecture. Perhaps the precision service PPS might become freely available in the future. GLONASS is also operational and freely available and offers higher performance than GPS, so its use in the baseline architecture could also be advantageous. Clearly, the advantages of interoperability include lower transition cost, re-use of existing equipment and the flexibility for GNSS 2 to evolve progressively without major disruption to existing services and so on.

In contrast, interoperability will probably place constraints on the design of a civil satellite navigation system, e.g. choice of operating frequency (GPS shares the radio spectrum with other services in Europe with the possibility of adverse radio interference). Also whilst GNSS 2 has any degree of dependence upon GPS and GLONASS, there remains the continuing risks associated with monopoly service providers and the technical shortcomings inherent in their designs which limit the quality of service they offer. In reality, there may not be a choice. Users will be reluctant – even opposed – to use any solution that requires another complete refit of equipment within ten years or so from the time they made the change from today's ground-based navigation infrastructure to GNSS 1. GNSS 2 receiver designs could have a multi-function capability to operate with either system, but that would increase cost. Therefore, it is suggested that at least the baseline system with its global coverage architecture should be compatible with GPS/GLONASS and endeavour to provide the flexibility for the regional and local level architectures to employ the most suitable technology to satisfy the application. It is expected there would be the opportunity of migrating some GNSS 1 technology to the new system.

3. system architecture.

3.1. *Key Design Objectives.* GNSS 2 must satisfy a wide range of user applications, but it is believed that the system should be designed in such a manner that it offers choices to the users to implement only those system functions and performance capabilities that are suitable and cost-effective for their operations. The studies that have been undertaken under the EU GNSS Support Task[2] clearly show that it is not cost-effective to have a single system performance standard for all users and all applications. GPS has already demonstrated that without any form of augmentation, the time and position data available on a global basis are adequate for many applications but, in general, fall short of the safety requirements where public transport safety is involved.

An optimized system design usually involves trade-offs, and the following are some of the factors that will need to be considered in order to finalize system design;

(a) development and operating costs
(b) complexity of ground, space and user segments
(c) technological risks
(d) upgradeability and maintainability
(e) maximum use of GNSS 1 investment
(f) safety performance targets
(g) approval and certification aspects (safety systems)
(h) backwards compatibility
(i) institutional issues.

It is important that the design enables a phased implementation of each capability in a cost-effective manner. The discussion presented earlier in this paper points to an optimum design architecture that would have three layers targeted to particular user applications. In particular, the architecture would be configured to provide three different levels of coverage and safety performance – global, regional and local. The global overlay service must be configured to have very good availability if it is to attract user confidence and investment in the system. Integrity is another important factor if users are to trust the information derived from the system. The study at Reference 1 showed that the maximum cost/benefit ratio for the aviation user is achieved by the addition of a wide area integrity monitoring overlay. The achievement of the appropriate levels of availability and integrity would be dependent mainly on the space segment – number of satellites, disposition of the constellation and the provision of a broadcast satellite integrity function. As already mentioned, accuracy need be no better than that offered by the GPS standard service. The target performance requirements for each level are shown in Table 2.

3.2. *Principal Architectural Features.* An outline of the proposed architecture to meet the performance targets is shown in Figure 2. The objective is to design an

Table 2. Summary of performance requirements

		Essential		
		Safety of life	Other	Non-essential
Global	Accuracy	10–100 m	10–100 m	10–100 m
	Integrity	10^{-7}/hr	10^{-2}/hr	10^{-2}/hr
	Availability	10^{-6}	10^{-5}	10^{-2}
Regional	Accuracy	1–10 m	1–10 m	1–10 m
	Integrity	10^{-7}/hr	10^{-2}/hr	10^{-2}/hr
	Availability	10^{-6}	10^{-5}	10^{-2}
Local	Accuracy	0·1–10 m	0·001–10 m	None
	Integrity	10^{-8}/hr	10^{-4}/hr	
	Availability	10^{-7}	10^{-4}	

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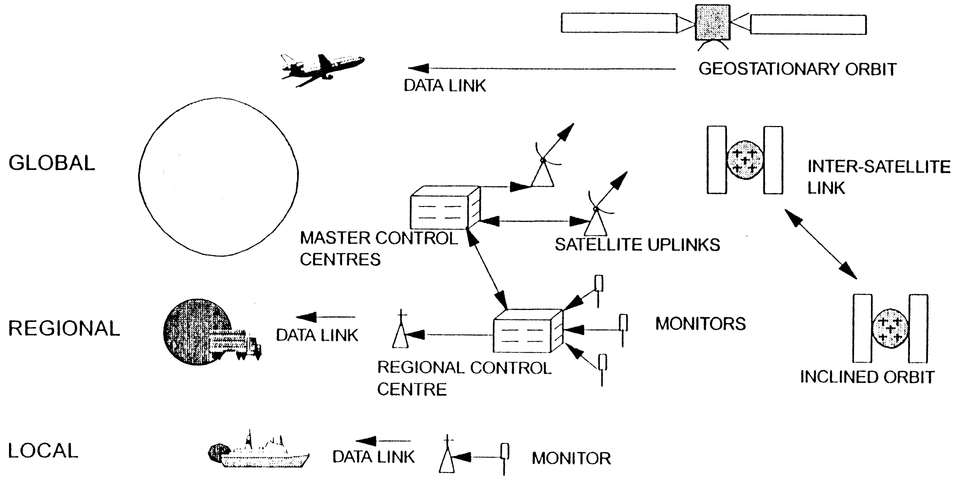

Figure 2. System architecture.

integrated system that is coherent and capable of an incremental development and implementation. The requirements of geometry mean the use of both geo-stationary and inclined orbit satellites in the space segment. Users wishing only to access the global area service only need to use the data transmitted from the satellite constellation. Access to the regional area integrity data can be either by satellite or terrestrial data links. To the maximum extent possible, the same ground components will support each level of the GNSS 2 network. Thus the regional area monitor stations will interchange information with the global area control centre and support the global service. This global area service is the one in which GNSS 1 can make the biggest contribution, possibly supplying geo-stationary satellites and a great deal of the ground infrastructure.

It is believed that more stringent safety-of-life applications are unlikely to be approved by regulatory authorities, without some form of independent monitoring. Supplementary components to the baseline architecture are targeted to specific groups of application where enhanced performance is deemed necessary.

The local area service will essentially be stand-alone, provided and operated by third parties, independent of the global/regional infrastructure which is operated by the international civil agency responsible for GNSS 2. These services will, of course, have access to the satellite and navigation data derived from the regional/global systems. Position, time and other data computed by the local monitoring stations are transmitted directly to local users by means of terrestrial data links. It is comparable to a number of maritime coastal services already in operation.

4. architecture safety assessment.

4.1. *Identification of Safety Risks.* Safety must be one of the principal considerations taken into account in the design of a system that will have a key role in public transport operations. There is a well defined and rigorous means to demonstrate a system is safe, reliable and fit to support an operational application. This is the safety assessment, an established technique employed in many industries where public safety is important. It is a structured approach and GNSS 2 will need to undergo this assessment if it is to support safety-related public transport applications. At present, there are no agreed and defined GNSS safety requirements

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Table 3. Relationship between effects, severity and probability

Effect	Normal	Nuisance	Emergency procedures Operating limitations	Significant reduction in safety margins Difficult for crew to cope with adverse conditions Some injuries	Large reduction in safety margins Crew extended due to work load and conditions Serious injury/ some fatalities	Multiple fatalities/ usually loss of aircraft
JAR 25 Probability	Frequent		Reasonably probable	Remote	Extremely remote	Extremely improbable
Category of effect	Minor			Major	Hazardous	Catastrophe

10^{0} 10^{-1} 10^{2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9}

Probability per hour

specified by any transport authorities but, in some cases, such as aviation, these will be needed for GNSS 1 and should be in place for all safety-related services for GNSS 2.

In determining safety requirements, the regulatory authorities invoke the principle that an inverse relationship should exist between the probability of an occurrence and the degree of hazard inherent in its effect. Table 3 shows the relationship between effects, severity and the probability of occurrence. Although this table illustrates the basis for airworthiness requirements related to aircraft and aircraft systems, it also provides a useful basis for analysing and making judgements about the risks associated with navigation systems such as GNSS.

To enable a judgement that the design and operation of a navigation system is safe and meets its specified performance requirements, the system designer must undertake a quantitative analysis which is derived from the performance requirements that circumscribe the navigation function and quantifies the risks to normal performance associated with elements of the system. A process is needed to establish what is an acceptable risk that the required performance may not be achieved and what contributions to that risk are associated with either the design or operation of the system.

An operational hazard analysis would be considered a normal requirement for any modern system employed for safety related applications. One example of an analysis used in aviation is reported in a certification study undertaken during the GNSS 1 programme initial phase.[5] This hazard analysis identified possible failure modes, including human errors and their effects. The analysis examined failure-initiating events and the recovery from failure processes, and related these to the target level of safety defined for the operation. As a consequence, a number of areas of concern were highlighted regarding the use of EGNOS as a 'sole means of navigation' system and recommendations made that would improve overall system robustness to failures. GNSS 2 will need to be analysed in the same way.

4.2. *Assessment Methodology*. Four steps have to be considered in establishing the acceptable probability of a safety-related occurrence in a system or sub-system. First, a policy needs to be defined for the overall level of safety considered to be acceptable and at which to aim. Second, the choice of parameters which adequately circumscribe the required safety performance sought from the system. Third, identifying and quantifying any mitigating factors which might minimize the impact of a hazardous occurrence. Fourth, defining the top-level requirements that will achieve the target safety level and enable subsequent partition of the risks appropriately to individual elements of the system.

It is recognized that the best way to control the overall accident or incident risk is to partition the risk to the principal causes and then try to control these individually. This top-down probabilistic approach avoids requirements being defined which are based on a worst-case analysis. In the air navigation field, this technique is already employed in analysing the safety risks in the approach and landing phase of flight. Risks associated with all the elements which might lead to hazardous failure are identified and partitioned in such a manner that there is full *tractability* between the overall target level of safety and the individual system elements that support the operation. The usefulness of this risk tree to the system designer is that he can analyse the risks and design the risk allocations into the system to achieve the particular performance characteristics required of each component of the system design. Where a formal approval process applies, it provides a means for assessing the safety of individual elements as well as the whole system. More importantly, this analytical approach provides evidence that safety related risks have been properly addressed.

5. transition to future system. Just as the transition from current navigational systems to GNSS 1 has to be justified on cost and benefit grounds, so the later transition to GNSS 2 must be similarly justified. There are many political and long-term economic arguments about dependency on foreign national monopoly providers and about letting any monopoly supplier situation develop. However, these are not factors that the individual user groups have much power to influence, and again are not matters that will come into the short-term cost–benefit analysis. Therefore, for GNSS 2 to show a positive cost–benefit ratio in a reasonable time period, there needs to be clear immediate operational benefits to cause users to switch to GNSS 2. In other words, GNSS 2 must allow users to do things they were not able to do with GNSS 1. This now reflects back into the proposed wide area augmentation systems; are they already too capable, so that there will be no argument for transition to GNSS 2?

Within the framework of GNSS 1, three separate satellite augmentation systems are being developed: EGNOS, WAAS and MSAS. Initial conclusions from the studies reported in this paper are that WAAS and EGNOS are too capable and therefore undermine support for a future GNSS 2. The maximum cost–benefit ratio for the aviation user is achieved by the addition of a wide area integrity monitoring overlay only. Wide area differential corrections and additional geo-stationary ranging sources may not be required. However, given the already substantial investment, it is inevitable that these three systems must at least form part of GNSS 2. Yet in spite of the investment being made, they will not be capable of satisfying all the user applications identified earlier in Table 1 – a consequence perhaps of political rather than technical or operational requirements driving the design.

The future availability of GPS and GLONASS without direct user charge, the continuation of degraded accuracy, the extent of user take-up of GNSS 1, the political scene, the response of regions outside Europe to GNSS and other factors merely confuse further any consideration of the transition. Nevertheless, a reduced-capability GNSS 1 would free some funding for GNSS 2, would allow for a speedier implementation of GNSS 1, and would leave 'clear water' between the capabilities of GNSS 1 and GNSS 2. If this conclusion were accepted, it would have the effect of changing the development priorities of the current wide area programmes, and altering the technical specifications.

GNSS 2 must evolve from GNSS 1 for the reasons stated earlier. It would be logical progressively to implement the civil global overlay (geo-stationary/inclined orbit satellites and associated ground segment) until independence from GNSS 1 is achieved. The regional and local systems would be developed along comparable time scales, in some cases perhaps evolving from parts of the GNSS 1 architecture.

No attempt will be made in this paper to forecast the likely time-scale or cost for the transition because there are too many imponderables. However if, or when, the worldwide availability of accurate navigation and position information becomes wholly dependent on GPS and GLONASS, a considerable risk to that service will remain until a civil-controlled system is in place.

6. conclusions. The principal conclusions on the planning and development of GNSS 2 which have been drawn from this paper are as follows:

(1) The system should be developed, owned and operated under civil, international control to overcome concerns about monopolistic or military ownership.
(2) The system must be safe in order that it can be approved for use in support of public transport applications. To demonstrate it is safe, the system should undergo a formal and structured safety assessment against published safety standards.
(3) GNSS 2 must be need-driven, and will only become a reality if it offers real additional capability over-and-above the planned wide area augmentation systems. The incremental benefits to the users must justify the additional costs of deploying GNSS 2.
(4) The optimum GNSS 2 architecture should be based on a three-layer concept whereby each layer satisfies a level of performance commensurate with a defined application for that layer. The three layers would comprise a baseline global overlay navigation service available to all users. The top layer should be capable of accommodating augmentation techniques to enhance and satisfy the performance requirements defined for the two lower layers of architecture.
(5) The regional and local levels of service should be capable of progressively higher levels of performance but smaller areas of coverage. These two architectures would be capable of supporting additional broadcast data which would support the specific applications which require it. The local area service should be a stand-alone sub-system, funded, operated and accessed by those users who require it.
(6) GNSS 2 should evolve from the techniques and technologies that will be available in GNSS 1, with the core component interoperable with GPS and GLONASS to enable a timely and cost effective transition to be undertaken. It should also make maximum use of the projected hardware deployment.
(7) Both space and ground segments should be developed in a progressive manner

over a period of time and each step should achieve a demonstrated performance and capability before implementing subsequent phases.

(8) The multi-national investment in three currently envisaged wide area augmentation systems are overly complex and still lack the capability to satisfy all the user applications. A reduced capability GNSS 1 would free some funding for GNSS 2, would allow for a speedier implementation of GNSS 1, and would leave 'clear water' between the capabilities of GNSS 1 and GNSS 2. The geo-stationary satellite ranging function should be considered as a regional component of a GNSS 2, rather than a necessary component of GNSS 1.

(9) It is suggested that to enable the benefits from GNSS 2 to be available to all user communities throughout the world, the development and maintenance of the global overlay might be funded with government support within each geographic region.

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key words

1. GNSS. 2. Satellites. 3. Design. 4. Safety.