Global Radionavigation – The Next 50 Years and Beyond

John M. Beukers

(*Beukers Technologies, USA*)

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Just 25 years ago, the author presented a paper at the 30th Annual Meeting of the United States Institute of Navigation (ION) entitled 'Radionavigation in North America, the Next 25 Years'. The paper received much attention and was given the ION's Burka Award for the best paper of the year. The author attempted to predict the worldwide implementation of Loran-C and Omega while acknowledging that satellite technology was on the horizon. 'Global Radionavigation – The Next 50 Years and Beyond' builds on the previous paper and is an attempt to define the future of global radionavigation based upon a mix of terrestrial and satellite systems. The time it takes for satellite systems and augmentations to mature and the reasons for this extended period provide the foundation of the paper. Also discussed are: the time to achieve a full constellation of space vehicles having signal specifications that meet the requirements for safety-of-life, the political complexities to achieve international harmonisation of service, and the use of a common worldwide protected frequency spectrum. The need for terrestrial complements is presented from the standpoint of supporting satellite systems and as a back-up in the event of loss of satellite services.

KEY WORDS

1. Radionavigation. 2. GNSS. 3. Loran-C.

1. INTRODUCTION. It was exactly 25 years ago that the author presented a paper at the 30th meeting of the US Institute of Navigation (ION) entitled 'Radionavigation in North America ... The next 25 Years'. Most would like to bury their prophecies but, in this case, there is something to learn from putting those thoughts on paper. The paper was selected as worthy of the ION Burka Award for best paper of the year. While this may appear a significant honour, it should be noted that 25 years ago there was only a handful of us at work in this discipline and recognition was certain for anyone with the courage to speak up on controversial issues.

The projections and conclusions put forward in the 1974 paper have turned out to be on target with two notable exceptions. Although the paper cautioned against over-reliance upon the VLF Omega navigation system because of the controlling position of the United States, it did not predict the premature demise of the system in 1997. The second exception, which is important for us today, was the failure to recognise the dramatic increase in capability and cost reduction of user equipment. With this

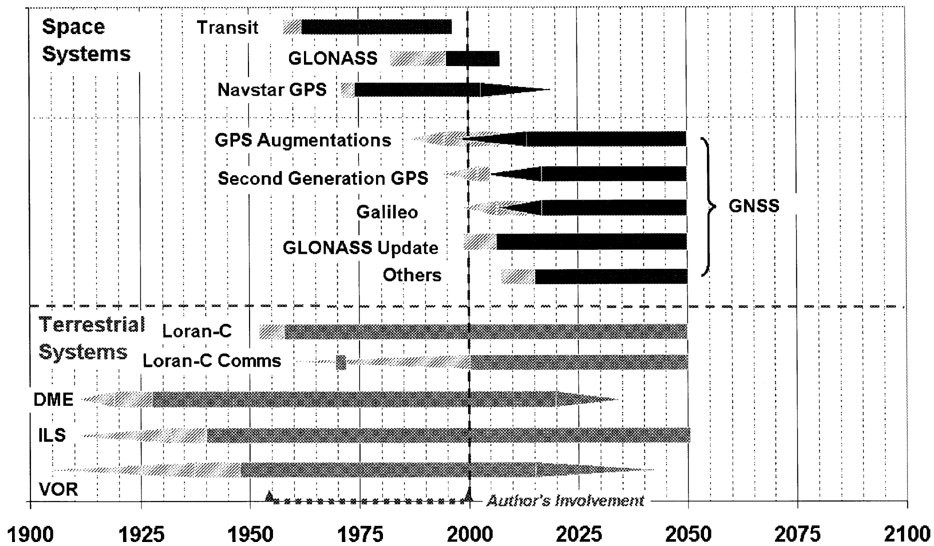

Figure 1. Historic dates and projections for radionavigation systems.

mixed success, the presentation today is another prophetic look at the future but with the advantage of 25 years of hindsight.

This paper is strongly biased by experience in the United States, but the principles, comments and projections are pertinent to the international community as it wrestles with decisions for the future of radionavigation. Figure 1 shows the historic dates and projections for radionavigation systems and is referred to throughout the paper.

2. RADIONAVIGATION LONGEVITY. History has shown, and the experience of today confirms that, no matter how much money or how many people are put to work on the development and implementation of a radionavigation system, it takes a very long time to reach operational status and become accepted. The road to maturity is long and fraught with delays. But once a supporting infrastructure and user community becomes established, the period of usage runs into many decades. One has only to look at VOR and ILS, both developments of the 1940s – with an even earlier beginning – to realise that a life of 100 years is not unreasonable. Today we are putting new ILS systems into operation and discussing the phase out of VOR over the next 10 to 20 years. The same is true for terrestrial hyperbolic systems that have evolved from systems developed prior to and used during World War II. Loran-C that was devised to overcome the deficiencies of earlier systems has been around since 1958 and will be with us for the foreseeable future. An exception to this is the worldwide Omega system that was deemed to have no further utility by the United States once the Global Positioning System became fully operational. Omega was terminated in 1997.

3. DEVELOPMENT AND IMPLEMENTATION. Why does it take so long from the drawing board to an operationally accepted service? Quite apart from the inevitable interruptions caused by controversies over funding, there is the underlying fact that no system ever devised has been perfect. It takes time to determine the imperfections, a process that is hindered by the natural desire by

developers to minimise problems for fear of the programme being cancelled. This prolongs the development cycle and deters investment in a supporting infrastructure. It then takes additional time for user equipment to appear and for a meaningful user community to evolve. Loran-C in the United States is a prime example of the chicken and egg situation. Following the transfer of Loran-C from the Department of Defense (DoD) to the Department of Transportation (DoT) in 1974, and designation of the service for the Coastal Confluence Zone (CCZ), it took a contract from the US Coast Guard for a low-cost receiver to jump-start the manufacturing support activity.

4. ADMINISTRATIVE STRUCTURE. As we attempt to introduce systems on a worldwide basis, international administrative complexities add to the implementation time and further delay user acceptance. Issues that are well known and have been debated for the past 10 years are still awaiting resolution. Questions relating to sovereignty, liability, spectrum protection, specifications and standards, as well as international agreements, remain pressing issues that continue to appear on meeting agendas.

5. POLITICIANS, POLICY AND PHYSICS. 25 years ago, life in the radionavigation community was comparatively simple. There were some of the frustrations common today, but government involvement was restricted to just a few agencies. Today, the money involved is several orders of magnitude greater than it was and the community a thousand times larger. The decision-making process for implementing new technology is now in the hands of politicians and accountants who are understandably poorly equipped to provide the much-needed leadership. In fact, matters of radionavigation policy in the United States have been stagnant for the past five or more years. The 1998 Federal Radionavigation Plan, now almost two years late, has yet to be published; there has been no announcement of the decision by DoT to continue the Loran-C service beyond next year; reports mandated by Congress have been sequestered by the Administration for more than a year; the General Accounting Office is in the process of investigating satellite navigation and the Office of the Management and Budget appears to have become the radionavigation czar. Studies, reports and investigations are seen to have replaced the decision-making process.

6. MARKET PROJECTIONS. The absence of leadership and decision plays havoc with market projections that already tend to be over-optimistic in both time-scale and magnitude. For example, the March 1992 issue of *Defense Electronics* carried a projection that by 1996 the military will have purchased $1 billion of GPS equipment; automobile usage would consume $3·5 billion; a further $1·4 billion would go to the marine market; aviation would pick up $652 million with a further $500 million going to other markets. The projections did not anticipate implementation delays and reluctance to equip during times of uncertainty. Further, perhaps more significantly, they did not anticipate the rapid fall in receiver pricing. The anticipated avalanche of orders never materialised and, with falling prices, margins have been eroded.

7. NEW TECHNOLOGIES – THE GPS EXAMPLE. The US Global Positioning System is a prime example of a complex new technology progressing

through the many stages of development and implementation, proving once again that there are no short cuts. The GPS constellation that was in development when the author's 1974 paper was written has just passed its 1024th week of operation. There can be no doubt that the current GPS constellation has proved what can be achieved using satellites for positioning and timing. However, a critical review of where we are today suggests that the current GPS and its augmentations is a forbear of what will become a robust service in the 2015 time frame. Both the US civil and military programs for GPS modernisation testify to this.

After 20 years of euphoric experience, we now recognise the vulnerability and deficiencies of GPS. Modernisation plans call for: additional frequencies, higher power, improved resistance to interference and jamming, an increase in the number of space vehicles and augmentation to provide integrity and improvement of accuracy. These are now design requirements on the front burner for which funding is being sought.

8. FUTURE OF SPACE SYSTEMS. Although limited in capability, the US Transit system demonstrated the feasibility of positioning from space, later to be confirmed by the Navstar/GPS programme with almost 25 years of operational experience. By the end of this period, the extraordinary performance of satellite technology has become recognised worldwide and is now legend. However, as GPS vulnerabilities became better understood, the operational period also brought into focus the questionable policy of total dependence on space. It is now clear that GPS as we know it today is an operational test bed for second-generation systems. Both the military and civil communities recently confirmed that GPS in its current embodiment does not meet the demanding operational, safety and security requirements for a satellite service.

Under the guise of a 'GPS Modernisation Programme' the US DoD and the US Federal Aviation Administration (FAA) are calling for a second-generation system having more power, additional frequencies and new codes. Chief of the Joint Program Office, Col. Neil McCasland, recently stated that the military will need three to four orders of magnitude resistance to jamming, calling for both an increase in satellite power and improvement in signal processing using new coding technology. These requirements were echoed in the report of a study undertaken by the Johns Hopkins University for the FAA. The FAA was quick to pick up on and publicise the conclusion of the study that stated sole-means use of GPS was technically possible with acceptable risk but less than forthright with the condition that to do so with safety could not be achieved with the current system. In fact, the report outlined the requirements for a second-generation system that included additional space vehicles with significantly enhanced capability.

The current GPS constellation will be phased out and replaced with a new generation of space vehicles. This will take 15 years. A not insignificant portion of this time will be taken up with international frequency spectrum negotiations, establishing requirements and obtaining the necessary project funding. Following satisfactory space vehicle development and manufacture, the constellation has to be replaced in its entirety before the second-generation performance can be realised.

In the meantime, the definition phase for the European Galileo constellation will have been completed and development started on both the space and control segments. Allowing for the inevitable slippage in the projected operational date of

2008, we might expect an operational Galileo constellation by 2015, about the same time that the second-generation GPS becomes operational.

The Russian GLONASS system, and its frequency allocation asset, will continue to play an important role, although it is not clear who will provide the support to maintain the Russian initiative. It is anticipated that signals from an upgraded GLONASS will be available by the end of the next decade.

Other States may decide to orbit their own constellation in the interest of national security and to be a player in the international GNSS. The decision to make this investment will be largely influenced by the actions taken by the European Union with Galileo and the progress towards a second-generation GPS by the United States.

Terrestrial and space-borne GPS augmentation for providing integrity, removing propagation errors and countering the effect of DoD's intentional degradation of accuracy, are in the process of being implemented worldwide. In some instances, notably the medium frequency beacons carrying differential corrections, the service is already operational in some areas. Satellite augmentation has a number of years to go and is being delayed by funding issues. The projection for completion of worldwide availability is 2020 with a gradual build-up to this status.

The dates projected may be regarded as pessimistic, but they are probably realistic. However, acceptance of the dates is not as important as recognising that a second generation of satellite technology is under development to mitigate the vulnerabilities of the current GPS that have surfaced since it became operational.

9. THE SOLE MEANS ISSUE. Following the announcement of Full Operating Capability of GPS, the US Government took the position that GPS and its proposed augmentations would provide a radio-positioning service for all modes of transportation and therefore all terrestrial federally-provided services would be turned off. The concept of GPS 'sole-means' was born. This policy was first publicly announced in the 1994 Federal Radionavigation Plan (FRP). It is said that the funding appropriations for GPS were approved on the basis that there were substantial savings to be realised by the phasing out of terrestrial services.

It was not recognised that GPS in its current form could not do the job. To make matters more challenging, it is becoming increasingly evident that even with second-generation systems of improved availability and immunity to interference, total dependence upon space may not be advisable and this has led to a reassessment of policy. The future mix of federally provided radionavigation services is now being addressed along with the cost of continued operation of terrestrial services.

10. FUTURE OF TERRESTRIAL SYSTEMS.

10.1. *Loran-C*. Of the terrestrial services to be discontinued in the United States, Loran-C has received by far the greatest attention. Congress, the Administration, various branches of the US Government, user organisations, and manufacturers have been at loggerheads over the future of Loran-C since the change in termination date from 2015 as stated in the 1992 FRP to 2000 that appeared in the 1994 issue of the document. The matter became an international issue at the time of the transfer of overseas Loran assets to host nations, which was made just prior to the announced change in termination date. These nations fully expected continued operation of Loran-C in the United States with on-going technical support and felt that they had been deceived.

Today, Canada continues to operate Loran-C while watching the policy shifts in the United States. The Northwest Europe Loran-C System consortium (NELS) is upgrading the control of the Loran-C transmitters for which it is responsible and adding data communications for wide area differential corrections for GPS/GLONASS/GNSS. In April 1999, the NELS Steering Committee agreed to a policy of Loran-C integration with European satellite services. The Far East Radionavigation Navigation (FERNS) consortium (China, Japan, Korea and Russia) provide Loran-C services over a wide area in the Far East, and Russia continues to provide Chayka (Loran-C) services with plans to integrate the system with the neighboring Loran-C services.

So why is there so much acrimony over Loran-C in the United States, and what is the future global role for the system? In the United States, Loran-C is regarded as a GPS spoiler and a hindrance to the transition to GPS. The system threatens the Administration's policy of GPS dominance. Further, since it is estimated that there are more than a million users of Loran-C in the United States, continued operation denies the GPS industry of a mass market. Adding to these negative factors is the cost of Loran-C transmitter upgrading and the ongoing expense of operation and maintenance. The result has been confusion and indecision, with the user community supported by Congress pitted against the Administration and government agencies.

But the current spat has little to do with the Loran-C service as a complementary asset to satellite systems. It is essential to recognise that Loran-C is the only terrestrial system that can provide a positioning, navigation and timing service should there be an interruption or failure of space-borne systems. Loran-C is a regional service covering high density populated areas and can be expanded on this basis to provide security where it is needed most. There are those who argue that satellite systems will never fail to deliver their specified radionavigation and timing service performance. As we become more and more dependent on signals from space, the remote possibility of failure carries with it an exponentially increasing liability that is perilous to ignore.

To the author, the continued operation of Loran-C is essential as a complement to satellite services, not only to provide a soft landing in the event of a failure of space-borne assets, but also to provide additional resources for satellite systems. It is therefore concluded that the Loran-C time line will be consistent with second-generation satellite services and become an integral part of the GNSS.

10.2. *Aviation Services, DME, ILS and VOR.* The 1994 and 1996 issues of the FRP identified a transition strategy from terrestrial aviation services to GPS, and the US FAA developed a satellite transition plan. More recently, the FAA has revisited this transition strategy by conducting an Investment Study, which is in its final reporting stage. In addition, the FAA in conjunction with the Air Transport Association, contracted with the Johns Hopkins University for a Risk Analysis Study to assess the feasibility of the use of GPS sole-means in the national airspace. An enormous amount of effort has been expended in considering the complex political, financial, operational and technical issues with due regard given to the users and supporting industry.

In summary, the original transition plan was over-ambitious and driven more by political and financial considerations than what could be achieved in the adopted time frame. The practical reality of introducing a revolutionary technology is now recognised, and the time-scale for the decommissioning of existing aviation services has been extended to coincide with the implementation of second-generation satellite services. In the author's the opinion, ILS will still be in use worldwide beyond 2050, while VOR and DME will have a shorter life with VOR the first to be decommissioned.

11. USERS AND EQUIPAGE. What does all this mean to the user? There is good news and bad news. The bad news is that the next 15 years is going to be unsettled and users, if they wish to derive benefits today, must be prepared to re-equip again when the new services become available. The good news is that in 15 years time, user equipment will have the capability of receiving and processing multiple satellite systems along with terrestrial services. A single box deriving input from combined antennas will become available at the price of today's single system receiver.

12. ROLE OF INERTIAL NAVIGATION. One of the keys to change in the future will be the development of low-cost, high-performance inertial units integrated with radionavigation systems leading the way to autonomous navigation. At present it appears doubtful that a $50–100 inertial unit will be possible; however, bearing in mind the erroneous projection of 25 years ago relating to user equipment, we have to leave this development as a distinct possibility.

13. BEYOND 2050. During the next 50 years and beyond we have to be prepared to run into some difficulties with space-borne platforms. This may be as a result of a high level of activity on the Sun, chain reaction collisions with space junk or meteorites, an unforeseen hardware or software malfunction or something we have not even considered. This would suggest retention of terrestrial complementary systems as part of the ongoing mix of systems. It would also suggest further research for alternative navigation systems based on natural phenomena. We know of the extraordinary navigation skills of wildlife on land, in the air, on and below the surface of the sea. Ants, snails, migrating birds, homing pigeons, fish, turtles, whales, butterflies – the list is endless – exhibit the ability to return to a specific location under all weather conditions and yet we have very little understanding as to how this is achieved. The Earth's magnetic field, gravity waves, smell, visual sighting and other phenomena are probably employed. We can be certain of one thing; none of our wildlife co-inhabitants of this planet rely upon a single system in making their incredible journeys. And further, the phenomena they employ are widely available and at no cost.

14. CONCLUSIONS:

(a) The original transition plan from terrestrial to satellite technology for positioning, navigation and timing was premature.
(b) The second-generation satellite systems will be more robust and will be fully operational in the 2015–2020 time frame.
(c) A gradual termination of some terrestrial systems can take place in step with the operation of second-generation satellites services.
(d) Loran-C must remain as the regional terrestrial complement for positioning navigation and timing for the foreseeable future

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