GLONASS, GPS and GALILEO Present and Future Aspects

Global Navigation and Hydrography is the theme of this issue. GALILEO has received a â€˜green lightâ€™, GPS has planned some important improvements and GLONASS has entered on a significant development programme. Time for HI to ask experts involved in each GNSS for their opinion on certain topics and finally to put the question: â€˜What is in it all for us surveyors?â€™

The experts interviewed are: Dr Vidal Ashkenazi (GALILEO), Dr Keith McDonald (GPS) and Dr Boris Shebshaevich (GLONASS).
The planned GALILEO-system involves some discussion in connection with already present GNSS systems and some of our questions had a political aspect. Dr Vidal Askenazi preferred therefore to give a total view in response to our questions; it is published under the last question.

Are you concerned that the different GNSS systems are competing in a political, technical and economic sense? If so, what do you observe or foresee as being the consequences regarding quality and availability of services to the user community?

Shebshaevich
Generally speaking, competition is an inevitable aspect of any human activity. GNSS are not excluded.
Actually, the appearance of GPS and GLONASS as an element of national security was strongly stimulated by political and technical competition in the years between 1970 and 1980.
The economic aspect emerged later (1990), when both GNSS systems became fully operational and their civil segments were declared available free of charge to the world community. Economic reasons are a serious guaranty of quality and availability of services now. Of course, there are certain negative consequences of competition but these are the same as for any other international business and shall be minimised by the same juridical instruments.

McDonald
The various navigation satellite systems are in many ways competing but, in my view, this is not a real concern. All systems need to justify their existence to their respective backers but there are significant benefits from the competition. The systems will work together to serve the users. The availability of several systems provides substantially improved capabilities, such that there is an enhanced value for each of the systems. An example of this is shown in Table 1, comparing the capabilities of GPS and GALILEO by themselves and in combination. There are advantages in accuracy, integrity, availability and flexibility. It is important that the system sponsors don't detract from this by attempting to establish unreasonable restrictions or monopolies on the use of their system.
Also, strongly based on the experience of GPS, (see Figure 1 for representative spacecraft), there is an economic stimulus to proceed with alternative navigation satellite systems. The only factors that may thwart the development of certain capabilities of these systems is firstly cost and, secondly, the desire on the part of system owners to deny use of the systems to their adversaries during times of hostilities. However, there is also strong interest in having the systems simultaneously available to friendly users. This implies, in general, some secrecy or other safeguards for a portion of the signal structure.

GPS is available free of charge to civilian users. Consequently, it has emerged as a major success for (US) industry and the user community has become addicted to it. As a trade-off, there is no guarantee that access remains unrestricted for reasons of (US) national security or defence. This might greatly harm friend and foe, both economically and security-wise Do you think that a guarantee should be given to the international civilian community that, at least in the case of severe danger to lives, a basic GNSS signal should be guaranteed? Or is there a national or regional responsibility for back-up facilities?

Shebshaevich
The Russian contribution to GNSS is GLONASS. Governmental plans adopted here consider international co-operation to be one of the basic principles of its development and employment.
The events of 11th September 2001 initiated investigations into additional back-up facilities. Ground-based, long-range navigation systems like LORAN-C are among potential pretenders. Russia has its own system of this type: CHAYKA. Its European, Northern and Far East transmitting station networks cover eastern Europe, the Arctic and far-eastern regions of Russia.

McDonald
Guarantees have been made by both the US and the Russian Federation for access to GPS and GLONASS. These guarantees were given in 1985 at a meeting of the International Civil Aviation Organization (ICAO), an arm of the United Nations. Both states then committed themselves to free access to their civil signals for a period of ten years and an indefinite period beyond this. Further, the US committed itself to informing the international community six years prior to any planned degradation of its GPS civil (aviation) service. This commitment has the strength of an international treaty and there has never been any interest, to my knowledge, in modifying this commitment. Of course, war conditions can change the character of any arrangements. However, the US has always guaranteed unrestricted access to its GPS civil signal (the C/A code on L1) and has no plans to discontinue it. In fact, the civil signal is required in many cases in order to acquire the military (P/Y) signal. Access to GPS augmentation services is open and available to all properly equipped users.
As a member of the US National Academy of Science Committee on The Future of GPS that studied access and many other issues

concerning GPS, I may point to several things that became clear:

- The use of Selective Availability (SA) to degrade the performance of GPS is not a sensible or viable way to deny access of GPS civil signals to adversaries. SA was reduced to zero on 1st May 2000 and there are no plans to change this
- There is consensus that the appropriate way for the military to control GPS operations in times of hostilities is to develop techniques that firstly deny the signal to adversaries in a region of operations and, secondly, accomplish this without adversely affecting civil uses in adjoining areas. A substantial programme to accomplish this is underway.

So, in summary, the current GPS civil signal will be available indefinitely without degradation. Additional, more capable civil signals (unrelated to any military use) are planned for the future at a lower frequency (L5 at 1176.45 MHz). The civil and military signal evolution for GPS is shown in Figure 2.

GNSS systems have an important function not only in navigation and positioning but also in (industrial) timing and synchronisation. There is little awareness of the increasing dependency of our society upon this â€˜by-productâ€™. Should GNSS timing signals become distorted or absent we might be faced with serious problems in communications, data networks (e.g. electronic financial transactions), energy distribution, remote control, etc. Do you consider this issue a subject of international, national or institutional concern?

Shebshaevich
GNSS-technique is penetrating all areas. It has no sense to stop this process and the only one opportunity is to minimise the risks. Here all possibilities shall be involved at international, national and institutional levels.
For example, a Russian Ministry of Telecommunication decree of 1999 prescribes use of dual system GLO-NASS/GPS receivers for Russian telecommunication networks synchronisation. Figure 3 illustrates the RIRT product set for this application, including 16-channel GLONASS/GPS OEM-board, smart clocks controlled by GNSS signals and capable of keeping time in holdover mode when satellite visibility is limited.
The Ministry of Transport is considering similar safety measures for Autonomous Identification System (AIS) transponders. One can imagine national regulations of this kind for critical applications.

McDonald
In my view, there has been considerable international, national and institutional concern in this area for many years. The international timing community has defined standards, techniques and practices that have been generally adopted. Many US power grids, cell phone systems and data networks are synchronised by GPS and have been for many years. The systems whose infrastructures are linked to GPS time typically have backup mechanisms, such as atomic standard clocks, that could provide reliable operation for an extended period following any GPS failure.

WRC (World Radio Conference ÃITU International Telecommunication Union-) 2003 is to allocate spectrum to GNSS. Do you think that the international GNSS society has sufficient power to claim the various frequencies so as to allow bandwidth for the different proposed system (extension)s. Economic preference for use of the spectrum unmistakably goes to satellite communications and the various communication services. Is there consensus to divide the allocated spectrum over the different GNSS systems in the most efficient way?

Shebshaevich
Satellite navigation and satellite communication are of equal importance. As a result, the existing systems are continuously improved within the frame of allocated frequency bands.
The current spectrum allocation provides fairly non-conflicting coexistence of satellite navigation and communication systems. By the way, to achieve electromagnetic compatibility with satellite communication systems, GLONASS frequencies are being shifted. Future satellite system(s) will integrate both global navigation and telecommunication functions in one and this will be the most efficient solution from all points of view.

McDonald
There is clearly a problem in that, traditionally, communications services take some priority over navigation services. However, WRC 2000 held in Budapest provided substantial spectrum for both US and European systems, such that additional requirements appear to me to be modest. Figure 4 illustrates the specific ITU radio navigation frequency assignments relating to GNSS services. As far as a consensus to divide the spectrum in the most efficient way is concerned: it is seldom that international bodies select the most efficient way. However, they normally are quite good at providing an acceptable solution that is workable to the parties involved. Obtaining consensus seems difficult and at times isn't possible, mainly due to political pressures.

A solution to many issues would be well-defined interoperability and, ultimately, merging/integration of the three global systems. Is there political will for this and has the technical feasibility been examined?

Shebshaevich
It must be agreed that a universal international satellite navigation system would be a perfect solution. To move in this direction, many non-technical problems must be solved. The level of co-operation in this field is still not sufficient to say it is feasible just now. But nevertheless we shall move forward step by step. It is much easier to integrate GPS, GLONASS and GALILEO in user equipment. And that is what we are doing now or shall do soon.

McDonald
The technical feasibility has been examined and does not appear to be a significant problem. The political will to provide well-defined interoperability specifications does not appear uniformly strong. Interoperability will probably first occur in the marketplace. Clever engineering will provide receivers that are interoperable and will meet the market demands of the user community.

Public Private Partnership (PPP) is a means to spare the taxpayer and involve private enterprises in building the system, service providing and supporting maintenance and upgrading processes. However, if an activity proves not profitable the continuity and quality of the system may be at stake, forcing governments to take over these activities indispensable to the public.

Shebshaevich
The GLONASS development programme for the next ten years makes economic efficiency the cornerstone of GLONASS prospective employment. The programme financing implies a federal state budget component and off-budget investments too. The most critical system segments are mainly government responsibility.
The responsibility for user equipment and augmentation systems development, as well as service providing, may to a considerable extent be non-state responsibility.
Many applications, for example natural resources exploitation, energy, and land cadastre management and control are attractive enough for business at local and private level.

McDonald
Many have had concerns over the workability or viability of the PPP arrangement planned for the development of GALILEO if this places a significant burden on the industry participants. A PPP can be successful and desirable if the states involved are willing to take over the lionâ€™s share of the funding and the management commitment. The private partnersâ€™ involvement will be strongly determined by the economics of the arrangement and how their business develops. This can be very problematic. Therefore, it seems to me that the governments involved will have to show leadership in providing the major part of the funding and a commitment to success.

Inmarsat started as an institution financially supported by member states and a stakeholder acting on behalf of the US. It has become transformed into a private organisation which is not dependant on financial support from governments. Do you think that GNSS could go the same way?

McDonald
No, in my opinion GNSS cannot go the same way. The financial arrangements for Inmarsat have been successful since they involve a product that can literally be sold by the bit (or byte) to end users. Navigation/position determination/time services differ in that they normally involve a multi-satellite one-way transmission to passive users. These costs are typically the responsibility of, and are paid by, user organisations or states. Possibly, public service and other encryption techniques may make this practical in the future. However, safety-related navigation services have in general been provided by government agencies. The provision of augmentation services primarily of a communications nature (e.g., downlinks of differential data) can and are provided on a fee basis.

Nautical and Aeronautical Charts are published for world-wide application. It is of major importance that users can rely on globally standardised geodetic and geographical references. For GPS the reference system is WGS84, which is continuously maintained and periodically updated. Tracking information is available and contributes to the ITRS. GLONASS and GALILEO are also using terrestrial tracking stations tied in to ITRS. Despite this communality, GLONASS and GALILEO use their own reference systems which differ slightly from WGS84. In addition, there is no satellite clock synchronisation between the three systems. Standardisation between the GNSS systems would make the individual system more robust and would economise on costs and effort. Is global co-operation and standardisation being considered and, if so, by whom?

Shebshaevich
A system of national standards and certification system development are important activities in the GLONASS development programme. Harmonisation of national and international requirements is one of the tasks. The necessity for co-operation with an international co-ordination body is evident. Meanwhile, modernised GLONASS spacecraft (SC) will transmit messages containing GLONASS-GPS time reference discrepancy.
Naturally, our GLONASS/GPS user equipment operates in both geodetic reference systems. Proper transformations do not introduce noticeable errors.

McDonald
Standardisation is normally desirable. However, there is some question as to whether or not inter-system standardisation would make the individual systems more robust or economise on costs or effort. It would make multiple systems easier to work with in combination but the costs and effort of maintaining an acceptable infrastructure for accomplishing inter-system standardisation and synchronisation could be significant. The WGS-84 reference frame for GPS is now nearly identical to the ITRF (to the cm level) and the computation of WGS-84 fundamental coordinates is accomplished using a number of stations also employed in ITRF computations. ITRF/WGS-84 coordination is not a real concern. Also, the Russian Federation has stated on a number of occasions that it plans either to provide GLONASS coordinate transformation data or change to the ITRF.
Clock synchronisation among the three systems can be established in a straightforward manner and their biases and rates can be easily distributed. These values are normally stable for periods of hours. Plans have been to provide this data to users so that corrections can be made to user clocks in much the same way that data message corrections are currently applied by the user to the various GPS spacecraft clocks.
Global co-operation and standardisation is normally considered by a number of international organisations, in addition to the national standardisation and measurement laboratories of individual states. These include ICAO for aviation, the IMO (International Maritime Organization), the International Telecommunications Union (ITU), the Bureau Internationale de Poids et Mesures (BIPM) and, in the US, the RTCA (formerly the Radio Technical Commission for Aeronautics), the AGU (American Geophysical Union), the Naval Observatory (USNO) Time Service, the National Institute of Standards and Technology (NIST) and others.

And, finally, â€˜What is in it all for us surveyors?â€™ Or, as we have rephrased this: â€˜Our readers look forward eagerly to applying the improvements to GNSS underway and promised. What specific benefits for hydrographic surveying and offshore positioning will, in your vision, be realistically provided by each individual system on its own and/or by combining/integrating the systems? Can you also give a time-scale for the new opportunities?â€™

Ashkenazi
To tackle this question it is important to give a brief summary of the history of satellite navigation and the reasons which led the European Union to embark on the GALILEO Project. In the 1990s, two independent satellite navigation systems were declared fully operational. They were GPS and GLONASS, designed to meet the respective military requirements of the USA and the USSR (now Russia). In the case of GPS, the system was later declared to be a dual-use asset for both civil and military users, although all its funding still comes through the US Department of Defence.
GPS was designed to provide predetermined levels of horizontal and vertical positioning accuracy 50 per cent and 90 per cent of the time, which were considered to be adequate for the requirements of military navigation on land, sea and air. In the 1980s, early civilian users of

GPS included yachtsmen, fliers of light aircraft and hikers. The advent of Differential GPS or DGPS soon increased the number of civilian users of GPS. With DGPS they could achieve quasi-instantaneous positioning accuracy in the order of 1 to 3 metres, so long as they were located within several hundred kilometres of a DGPS reference station and received its broadcast differential corrections. However, the real breakthrough for civilian users of GPS came with the development of the Carrier Phase Positioning technique, first proposed by two radio astronomers from MIT. This was the beginning of centimetric GPS, which led to hundreds of applications ranging from geodesy, geophysics, oceanography, land and offshore surveying, to timing, meteorology, agriculture, fisheries and space. GPS became an essential measurement tool for monitoring both the natural and the built environment.
This very wide variety of applications did not include safety-critical transportation. There were, of course, some general transport applications, such as fleet monitoring of trucks, taxis and cargo boats, but none involving aircraft landing or railway signalling. GPS, which was designed for military use, could not on its own deliver the tight requirements of accuracy, integrity and continuity of service essential for safety-critical applications. The missing ingredients were not within GPS itself, but external to it.
The breakthrough in meeting this demand for extra accuracy, integrity and continuity came with the development of the Wide Area Augmentation Systems: WAAS in the USA, EGNOS in Europe and MSAS in Japan. Wide-area systems consist of one or more geostationary satellites which provide a platform for the broadcast of differential corrections and continuous integrity messages coming from a dense network of ground-based satellite tracking stations.
However, there still remains the possibility of critical failure of GPS. Some of this risk can be alleviated either by coupling GPS with other well-tested backup systems, such as INS and VOR/DME for air navigation and Loran-C for marine navigation, or by installing dense LAASs which include pseudolites emitting GPS-like signals. However, the concern for â€˜what happens in case of unintentional or intentional failure of GPSâ€™ still remains. How can one certify a navigation system for safety-critical civilian navigation when it is basically under the control of a single country and the requirements of its military establishment, however well-intentioned these might be?
Hence the European GALILEO System, which is being designed to be fully compatible and interoperable with GPS but will be operated under the civilian control of the European Union. What difference will GALILEO make to hydrographic surveying and offshore positioning operations which, barring some exceptions such as ship docking, cannot be considered strictly safety-critical transportation operations as are aircraft landing or railway signalling?
GALILEO will offer four types of service:

- Open Access Service (OAS) which, like the GPS Standard Positioning Service, will be freely available for mass-market applications
- Commercial Access Service (CAS), which will involve encrypted value-added data in the signal, providing local augmentation services, integration with communication networks, etc.
- Safety of Life Services (SAS), which will provide additional integrity for safety-critical applications in civil aviation, marine navigation and train signalling
- Public Regulated Service (PRS), which will carry encrypted signals under EU government control, providing greater continuity of service for public service applications, such as police, fire, customs etc. To fulfil these requirements the signal will be designed to offer better resistance to interference and jamming
  From the offshore positioning community's point of view, GALILEO will offer some distinct advantages. To begin with, it will double the number of available satellites, automatically increasing accuracy and integrity and providing better coverage and therefore better protection against masking in difficult offshore environments. To achieve this, the GALILEO signal will have to be both fully compatible with GPS (ie non-interfering operations for the benefit of end users) and offer an acceptable level of interoperability, including with GPS (e.g. a fully compatible geodetic coordinate datum and timing system).
  Another issue of importance to the offshore community is the type and nature of the value-added data in the GALILEO CAS signal. Will CAS be offered by the GALILEO operator or be sub-contracted to private companies who will then provide the interface with different user communities? GALILEO also proposes offering a certain level of service guarantee, an attribute which would distinguish it from GPS, which offers a completely free service with no guarantees.
  The commissioning of GALILEO in 2008 or soon afterwards will open a new chapter in satellite positioning and navigation, with new opportunities for commercial exploitation and increased competition. It will also introduce a favourable environment for generating new ways of using these multiple sources of satellite data for better solutions and an even wider range of applications.

Shebshaevich
To my mind, two development trends will provide the main new opportunities for GNSS applications, hydrographic applications in particular:

- Progress in GNSS functional quality
- Progress in GNSS application techniques

The first will make the GNSS function more accurate, available and reliable for mass application. The second will result in the GNSS function penetrating all human activities in which accurate positioning and timing are attributes of event description.
Functional improvements in GLONASS are based on its space segment, ground segment (including augmentation systems) and user segment modernisation and development.
Starting from the year 2003, modernised GLONASS SpaceCraft (SC) will be launched with an increased 7-year active life cycle, making available two civil signals. The GLONASS Development Program implies a reconstruction of a constellation of 18 orbital SC in 3-4 years. After that the space segment will be restored by the next generation of GLONASS SC, currently in the design phase, with a 10-12 year life cycle, reduced mass to enable simultaneous launch of six SC and three civil signals available to users (Figure 5). The orbital constellation improvements, along with ground control segment improvements, will provide the availability of a level of several meters accuracy on a global and continuous basis.
Over ten years, coastal regions shall be successively covered by about thirty GLONASS/GPS differential reference stations based on middle-wave marine beacons. About 25 differential stations shall operate on the main rivers and lakes at the same time. The main ports shall be equipped by Autonomous Identification System (AIS) ground stations. Long-range navigation system CHAYKA will be modernised to provide for differential correction transmission capability. These measures will give about one metre accuracy, together with integrity monitoring and notification for safe navigation and reliable offshore positioning.
The user equipment segment is being modernised and is growing rapidly. The shipsâ€™ models of GLONASS/ GPS user equipment, designed and mass-produced by the Russian Institute of Radionavigation and Time, are presented on Figure 6. They include GLONASS/GPS OEM-products of business card size for integration in cartographic systems, AIS and completed devices for autonomous

usage and for coupling with cartographic systems. All of these are 16-channel universal GLONASS/GPS receivers with code and phase measurements capable of receiving and processing WAAS, EGNOS and MSAS signals and data. Completed devices integrate marine beacon signal and differential data receiving functions. Next generation models will also integrate a LORAN-C/CHAYKA extension. GALILEO integration is planned beginning from 2007.
Next generation GLONASS/GPS user equipment, available in two years time, implies a â€˜System On Chipâ€™ (SOC) design approach. As a result, power consumption and costs will be significantly reduced, becoming reasonable for new mass applications not before feasible; for example, monitoring of the geographical environment. This might include ocean and sea, ice cover and iceberg dynamics, ocean-atmosphere interaction processes, tsunami and earthquake forerunners, etc.
Global positioning and telecommunication combined in thousands of cheap, compact, autonomous monitoring platforms either fixed, manoeuvrable or drifting may, in several years time, become the basis for global and continuous process monitoring.

McDonald
The time-scale for the new opportunities has been configured but is sensitive to the vagaries of annual funding and changing priorities. The schedule for GPS is reasonably clear at any time but is a moving target. Recent delays have surfaced because of US (and other states) plans to mitigate international terrorism, in addition to large expenditure in preparation for a possible second Gulf War. These circumstances give priority to operations (receivers, installations, personnel), as opposed to system improvements, e.g. system modernisation and GPS III (the next generation GPS spacecraft). The schedule for GPS III slipped by two to three years this past January. Other impacts will likely occur.
This delay in GPS modernisation (the main elements of which are shown for the GPS Block IIF spacecraft in Figure 7) may be good news for GALILEO in that the window of opportunity for GALILEO may now be significantly wider. This window is the time interval during which GALILEO will have significantly improved performance capabilities over GPS. It relates primarily to the time-span between the start of operational capabilities for GALILEO and the establishment of modernised civil GPS operational capabilities. The new GPS civil L5 signals (I5 and Q5 at 10 Mbps) may not now be available until the year 2015 or later, which provides GALILEO with a window of about five to seven years or more, depending upon when it becomes operational (see Figure 8).
A summary of the GPS capabilities to be provided to users in the future is given in Table 2. Many of these will have a significant impact on the accuracy, speed, timeliness and coverage offered to the hydrographic professionals by GPS, GALILEO and GLONASS.

Abreviations Used

- GNSS: Global Navigation Satellite System
- ITRS: International Terrestrial Reference System
- ITU: International Telecommunications Union
- LAAS: Local Area Augmentation System
- LBS: Location Based Services
- PPP: Public Private Partnership
- RIRT: Russian Institute of Radio navigation and Time
- RTK: Real Time Kinematic
- WAAS: Wide Area Augmentation System
- WRC: World Radio Conference