WHITE PAPER

# GPS MODERNIZATION, GLONASS AUGMENTATION AND THE STATUS OF GALILEO – BENEFITS FOR HEAVY AND HIGHWAY CONTRACTORS

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**APRIL 2007**

## INTRODUCTION

*The US Department of Defense is currently in the process of modernizing GPS (Global Positioning System) with two new civilian satellite signals. At the same time, the Russian Federation has indicated renewed support for the GLONASS constellation of positioning satellites. Finally, a consortium of European civilian manufacturers are currently planning and implementing the European Galileo Navigation System – as a civilian controlled counterpart to the US and Russian-administered GPS and GLONASS navigation systems.*

*These three concurrent developments present tremendous opportunities for the high accuracy construction industry.*

*As a technology and industry leader, Trimble is committed to providing the construction industry with the latest information on GPS modernization, GLONASS constellation improvements, and the development of Galileo.*

*In this white paper, we will outline the use of modernized GPS signals and GLONASS signals, review the Trimble GPS+GLONASS[1] construction solutions, and demonstrate how Trimble technology is leading the industry in bringing the benefits of both navigation systems to the heavy and highway contractor.*

## A SHORT HISTORY OF THE GPS, GLONASS, AND GALILEO SYSTEMS

GPS was developed in 1973 by the US Department of Defense (DoD) to provide positioning, timing, and navigation signals to the US military and civilians worldwide. The constellation of 24 operational satellites has been reliably maintained by the US DoD since it was declared operational in 1993. In fact today there are 30 satellite vehicles in the constellation. The US DoD is currently investigating changes that would allow more than 32 SV's to be active at any one time.

The current spacing of the satellites in orbits is arranged so that a minimum of 5 satellites are in view at any given time.

To support the current constellation of satellites in space, there is a worldwide satellite network consisting of five monitor stations and four ground antenna stations. The monitor stations are spread around the globe to allow continuous tracking of the satellites by specially designed GPS receivers. The data from these receivers is used to assess the health of each satellite.

The GLONASS system is a counterpart to the US Global Positioning System managed for the Russian Federation Government by the Russian Space Forces and operated by the Coordination Scientific Information Center (KNITs) of the Ministry of Defense of the Russian Federation.

As with GPS, the GLONASS constellation is used for both military and civilian purposes. The spacing of the GLONASS satellites in orbits will be similarly arranged so that a minimum of 5 satellites are in view at any given time.

The European Galileo Navigation System is the European equivalent navigation system being built by a five-nation consortium including Airbus-owner EADS, France's Thales and Alcatel-Lucent, the UK's Inmarsat, Italy's Finmeccanica, Aena and Hispasat of Spain, and a German group led by Deutsche Telekom. Galileo is tasked with multiple objectives, including to provide a higher

precision to all users than is currently available through GPS or GLONASS, to improve availability of positioning services at higher latitudes, and to provide an independent positioning system upon which European nations can rely even in times of war or political disagreement. The current project plan has the system as operational by 2011-12, three to four years later than originally anticipated.

Unlike GPS and GLONASS, Galileo is controlled by civilian administration, not the European military systems, with the majority of the constellation development and all of its maintenance being funded by commercial capital.

Galileo is designed to have a 30-satellite constellation (27 plus three spares), as well as a complement of ground station equipment. These satellites will orbit at slightly higher altitudes than GPS, but the operating principles are essentially the same.

The proposed constellation is designed so that at least eight satellites will be in view at all times.

All of this is behind the scenes for the construction contractor using GPS. But since the introduction of advanced positioning instruments, GPS technology has enormously impacted the construction industry and how contractors carry out their everyday tasks. In particular, since the introduction of RTK (real-time kinematic) positioning by Trimble in the 1990s, contractors have experienced a huge leap forward in accuracy, efficiency, and productivity. Additionally, today's cable-free, all-on-the-pole systems from Trimble are smaller, lighter, more productive, and significantly easier to use than ever before.

## GPS MODERNIZATION

Manufacturers developing precise positioning solutions for the construction industry often refer to "GPS Modernization". So what is GPS Modernization? And how will heavy and highway contractors benefit from changes that are underway?

From the construction contractor's perspective, GPS Modernization is primarily the addition of the L2C code and L5 signal to the GPS satellite constellation. But before expanding on the new benefits to contractors, it is important to understand the DoD program for the continuing development of GPS.

For heavy and highway contractors and site surveyors, the successful launches of GPS 2R-M1-satellites, capable of transmitting L2C signals, represent a significant first step in the GPS Modernization Program planned by the US DoD.

Prior to the development of the L2C and L5 signals, GPS satellites transmitted two carrier frequencies—L1 and L2—both of which contain pseudo-random codes that provide positioning, timing, and navigation information. These codes enable GPS receivers to track several satellite signals at the same time, so that precise positioning can be calculated anywhere on earth.

Initially the L2 code was reserved for military use only, and civilian contractors could only directly access the L1 frequency. Now with the L2 code and dual-frequency capability receivers, real-time measurements are far more reliable and accurate.

The L2C nomenclature stands for civilian signals transmitted from the satellite on its L2 carrier. It includes a more sophisticated code that modern receiver technology is capable of utilizing, providing generally more robust results.

The new L2C signals translate into stronger and more reliable GPS guidance or control of construction machines. L2C will support faster acquisition, lower code-noise floor, better isolation between codes, reduced multipath errors, and better satellite cross correlation properties.

The DoD GPS Modernization program also includes changes on the ground with the ground control "monitoring" segment. Six GPS monitoring stations have been added to the five previously existing stations which made up the GPS monitoring network. This densification of the ground network provides improved tracking of all GPS satellites, resulting in more thorough analysis and timely adjustments to the constellation.

## PREPARING FOR THE FUTURE

As part of the decade-long GPS Modernization program, the US DoD plans to launch an entirely new GPS satellite with an additional L5 signal in 2007. The L5 frequency will provide an even higher power level, which will greatly expand GPS capabilities for non-military use. Broadcast at 1176.45 MHz, the L5 frequency will also have a larger bandwidth, mitigating radio frequency (RF) interference and reducing errors from the ionosphere. A full compliment of L5 broadcasting satellites should be in orbit by 2014.

## GLONASS IMPROVEMENTS

The Russian Federation has been gradually replenishing the GLONASS constellation in recent years after the system fell into disrepair following the collapse of the Soviet Union. Excluding 3 new satellites launched December 25, 2006, there are currently 10 operational GLONASS satellites plus 6 more that are temporarily turned off.

Russia currently plans to have 18 satellite vehicles in orbit by the end of 2007 and a full system of 24 operational satellites by 2009.
With only 10 satellites currently operational, GLONASS does not work well as an independent positioning solution for high accuracy construction applications. However, if it is used as a supplement to GPS and the Trimble RTK engine, GLONASS does provide more reliability and more satellites in view throughout the day. The additional GLONASS visibility is often enough to overcome tough construction environments and the standard down times when using GPS-only for RTK.

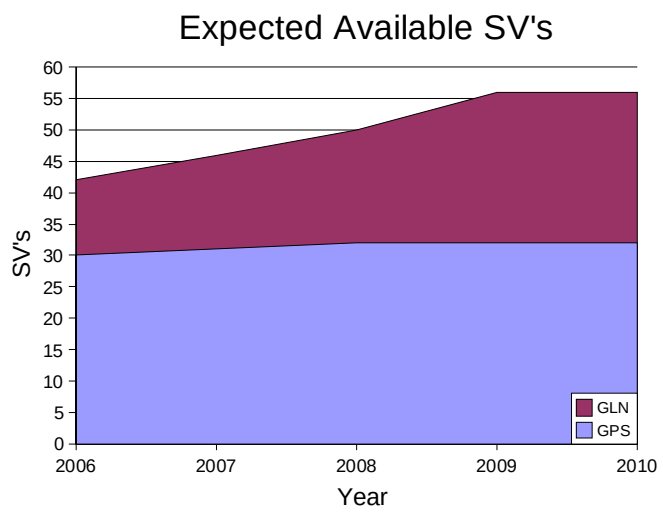


*Illustration 1: the projected availability of GPS and GLONASS satellites over time*

## THE DEVELOPMENT OF GALILEO

The first European Galileo Navigation System prototype vehicle was launched on December 28, 2005 and began transmitting signals in January 2006.

Although the Galileo schedule has experienced various administrative delays, the first "live" satellite is currently scheduled for operation in 2008.

According to its project schedule, Galileo will reach full operating capacity in 2011/2012. The schedule calls for 4 operational/production satellites to be launched in 2008 as well as completion of the ground monitoring and maintenance stations. With these components in place, final validation of the system and design will be made before launching the entire constellation.

## MORE SIGNALS = MORE BENEFITS TO HEAVY AND HIGHWAY CONTRACTORS

When the L5 carrier is launched, there will then be three GPS carriers: L1, L2 and L5, providing seamless satellite coverage. The entirely new L5 satellite, called Block IIF, will provide a higher power level than the other carriers, and it is anticipated that the capabilities of RTK systems will be significantly boosted, providing additional benefits to contractors.

The L5 signal is expected to provide much faster and reliable initializations, especially on longer baselines. Simulations have indicated that the initialization performance at a 60 mile baseline (96 km) will be similar or better than that of receivers using older RTK processors at 6 miles (9.6 km).

| The L2C … | provides this… | and results in … |
|---|---|---|
| Advanced public code structure | Better performance with weak signals | Better acquisition and tracking in challenging conditions |
| | Receivers will utilize the more sophisticated code to lock onto satellite signal stronger | Provide more robust result that is less likely to lose initialization |
| **The L5 …** | **provides this…** | **and results in …** |
| New third band with civilian code | Four times more signal strength than L2 | Stronger reception and significantly reduced effects of multipath |
| | Enhanced integer ambiguity resolution | Significant improvements in initialization speed, operating distance and reliability |

For now, additional satellite signals from the L2C frequency are providing heavy and highway contractors with the opportunity to experience improved accuracy, range and performance with fewer outages. It is expected that contractors working in tough GPS environments – near trees and buildings or in deep cuttings such as mines, trenches or landfill sites – will experience dramatic improvement. Technically, the L2 measurements are more robust, making GPS observations even more reliable.

In open environments, GPS-only solutions will generally provide adequate coverage for accurate positioning. The addition of GLONASS tracking in machine control and site positioning solutions provides value in the areas with obstructed view.

Heavy and highway contractors also benefit from the 19 GLONASS satellites, which were placed in orbit by the Russian Federation. The GLONASS constellation of active satellites continuously transmits coded signals in two frequency bands (L1 & L2), which can be received by users in any region of the Earth's surface to identify position and velocity in real time based on measurements.

## REMAINING AHEAD OF THE CURVE

With each new development in the GPS, GLONASS, and Galileo systems, Trimble has been several steps ahead in providing future-ready technology for the heavy and highway contractor. For example, when the US DoD first announced the GPS Modernization Program in 1999, Trimble began working on receiver technology capable of supporting both L1 and L2 civilian signals – resulting in Trimble R-Track technology. The technology is based on a new 5th generation Trimble integrated circuit inside the GPS receiver, which accommodates the new L2C signal structure.

This new integrated circuit enables:

- L1 and L2 carrier phase measurements with low noise and less than 1 mm precision
- Increased signal-to-noise ratios for L2C satellites
- Maximum multipath error reduction
- Superior low-elevation tracking

## GALILEO PROGRESS

Trimble Construction Division is carefully monitoring the ongoing development of the European Galileo Navigation System. To date, Trimble has been engaged in the research and development required to keep pace with the development of the system. The company has already successfully tracked the Galileo test satellite and will continue to monitor the status of the Galileo Interface Control Document (ICD) as the viability of the constellation becomes more apparent.

When details of further implementation emerge, Trimble will evaluate usefulness to the heavy and highway contractor and will respond accordingly.

## GPS+GLONASS = PRODUCTIVITY BENEFITS ON THE JOBSITE

With the ability to utilize satellites from both GLONASS and GPS, the minimum number of satellites a contractor can see in the sky will increase from five to nine, and the maximum number of visible satellites will increase to sixteen.

More satellites in the sky will lead to better job site productivity. Here's why:

For most open environment construction work, a GPS-only solution is sufficient for accurate positioning and machine guidance, but in more challenging conditions there may not be enough usable GPS satellites to fully meet the demands of real-time, centimeter-level accuracy, for instance, in wooded areas, near buildings, and in urban canyons.

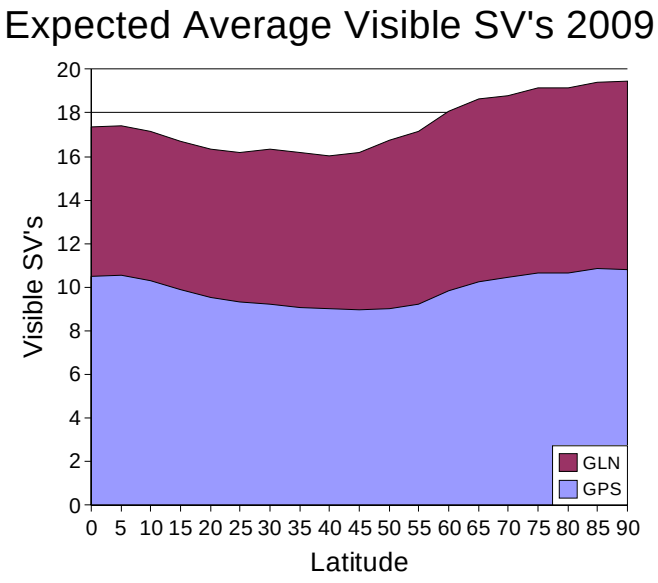


*Illustration 2: projected average number of satellites available through GPS and GLONASS in 2009.*

This is where increasing the number of satellites usable via GLONASS augmentation adds value in two ways:

- less RTK blackout, and
- increased probability of good satellite geometry.

With more satellites in orbit, there is a greater probability that a user will see enough satellites in the sky, and in the right locations, to maintain initialization when passing by an obstruction such as a high wall or bridge. If signal lock is lost, Trimble GPS+GLONASS solutions will help quickly regain accurate position without the delays sometimes experienced with GPS-only solutions.

| More satellites means … | And results in… |
|---|---|
| Less RTK blackout on challenging job sites | Reduced downtime through loss of initialization |
| Increased probability of good satellite geometry | Ability to work in locations and at times previously not possible |

On the construction site, that means less idle time caused by machines and workers waiting for positioning equipment to reinitialize and re-gain lock.

That also means less down time in the work day and more productivity.

## The Trimble RTK Engine

**What is Real-Time Kinematic (RTK)?**

- RTK refers to the use of GPS and/or GLONASS signals with real time messages provided by a reference station.

**How does RTK work?**

- RTK works by determining the precise difference between measurements at the base and the rover; the process of getting centimeter-level accuracy is called initialization.
- To get initialized, RTK needs a minimum of five satellites and works best with more. In usage mode, RTK can operate with four satellites.
- RTK requires a base station be placed on a fixed point and one or more mobile receivers within a twenty kilometer range of the base station.
- The base station transmits corrections via radio to the mobile receivers in the field. A typical radio link required for RTK is in the UHF or 900MHz spread spectrum radio.
- RTK blackout may occur when the sky view gets obstructed, and a user is unable to acquire the minimum of five good satellites it takes to initialize. The addition of GLONASS to construction positioning usage decreases the likelihood of experiencing RTK blackout.

**Why is the Trimble RTK Engine the industry leader?**

- Trimble pioneered the commercial use of RTK back in 1992.
- Since that time, Trimble has worked extensively to decrease initialization times, reduce the number of initialization losses with four satellites visible, and lower the likelihood of gaps in coverage during periods of poor geometry.

## TRIMBLE GPS+GLONASS CAPABLE PRODUCTS FOR CONSTRUCTION

In keeping with its industry-leading technology position, the Trimble Construction Division has capitalized on the new integrated circuit technology and developed three new products to take advantage of GPS+GLONASS signals. We are now providing the benefits to the heavy and highway construction contractor.

## TRIMBLE MS990 SMART GPS ANTENNA

The Trimble MS990 Smart GPS Antenna is the only commercially available integrated smart GPS antenna that offers the performance enhancements of a new Trimble RTK engine and supports the newest GPS and GLONASS signals.

Each unit contains a GPS+GLONASS receiver, antenna, and shock isolation system all in a single housing. It is designed specifically for installation on the blade or cab for use with Trimble GCS900 3D Grade Control Systems.

The Trimble MS990 replaces traditional GPS receiver and antennas and the need for specialized antenna cables. The elimination of cables improves GPS and GLONASS signal strength, reliability and durability in the harsh construction environment, simplifies installation and service, and ensures faster real-time positioning.

The Trimble MS990 also uses the advanced Trimble RTK engine to provide faster system initialization times when satellite lock is lost. This allows the Trimble GCS900 Grade Control System to increase machine

productivity and utilization in tough areas of the construction jobsite, where tree canopies or other obstructions may exist.

The Trimble MS990 supports the L2C and planned L5 modernized GPS signals, improving performance of the Trimble GCS900 Grade Control System at longer baseline lengths. Combined signals from GPS and GLONASS reduce system downtime when satellite availability is obstructed, such as when working against high walls or in deep cuts.

## TRIMBLE SPS880 SMART GPS ANTENNAS

A key component of the Trimble Site Positioning System, the Trimble SPS880 Smart GPS Antenna uses satellite signals to compute its exact location and give contractors an easy-to-use, wide area measurement system for a variety of site preparation and grade checking applications. The Trimble SPS880 can be used as either a rover for site measurement and stakeout, or as a base station for site measurement and machine control operations.

The Trimble SPS880 supports L2C and is ready to support the L5 signal when available. It also tracks signals from GLONASS, making it ideal for contractors who work in tough areas of satellite coverage. Trimble GPS antennas are also ready to receive all planned sources of GPS corrections, for reduced downtime and increased productivity on the job site.

## TRIMBLE SPS850 MODULAR GPS RECEIVERS

The Trimble SPS850 Modular GPS Receiver is ideal for semi-permanent or permanent setups, marine-based applications, as well as rover applications. The antennas can also be mounted in a marine vessel or on a site supervisor's vehicle.
The SPS850 receivers combine the radio and GPS receiver in a single housing, allowing contractors to secure the majority of their investment inside a site trailer or carrying case, protected form the elements and/or theft, leaving only the radios outside.

Versatile Trimble SPS850 GPS receivers are a future-proof investment; they are designed to receive all current and future satellite signals, including GLONASS and the L2C and L5 signals of modernized GPS.

## CONCLUSION

The next decade will see many changes in the technology required for the construction industry. The L2C and L5 signals that are part of GPS Modernization will present contractors with opportunities for more robust satellite tracking. They also demonstrate a commitment by the US DoD to support the many civilian GPS users worldwide, of whom the construction industry represents an ever growing percentage.

The Russian GLONASS system has a renewed commitment to quality by the Russian government, and additional satellites provide beneficial augmentation to GPS in difficult environments.

The Trimble MS990 Smart GPS Antenna, the Trimble SPS880 Smart GPS Antenna, and the Trimble SPS850

Modular GPS Receiver have been developed to take advantage of all the emerging positioning signals. They also represent Trimble's commitment to providing heavy and highway contractors with the most technically advanced solutions available in the marketplace.

Most heavy and highway contractors intend to use their positioning equipment over several years to maximize training and equipment investments .Those purchasing a receiver today – whether for earthmoving or site positioning – should take the changes available in GPS+GLONASS products into consideration.

Modernized signals = More construction productivity

- More robust performance in tough GPS conditions such as under tree cover, in deep cuts or mines, and near buildings.

Additional Satellites = Improved performance

- Better range and higher accuracy at range
- Operation with fewer outages
- Better satellite geometry

By choosing a Trimble GPS+GLONASS solution, customers can rest assured that these changes have already been taken into consideration by Trimble. A Trimble receiver that is ready to receive L2C, L5, and GLONASS signals without upgrade will protect their investment for many years to come and ensure maximum accuracy and productivity throughout the lifetime of the equipment.

[1] *The Trimble Construction Division employs the phrase "GPS+GLONASS" to describe products that currently track modernized GPS signals from the US system and GLONASS signals from the Russian constellation.*

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