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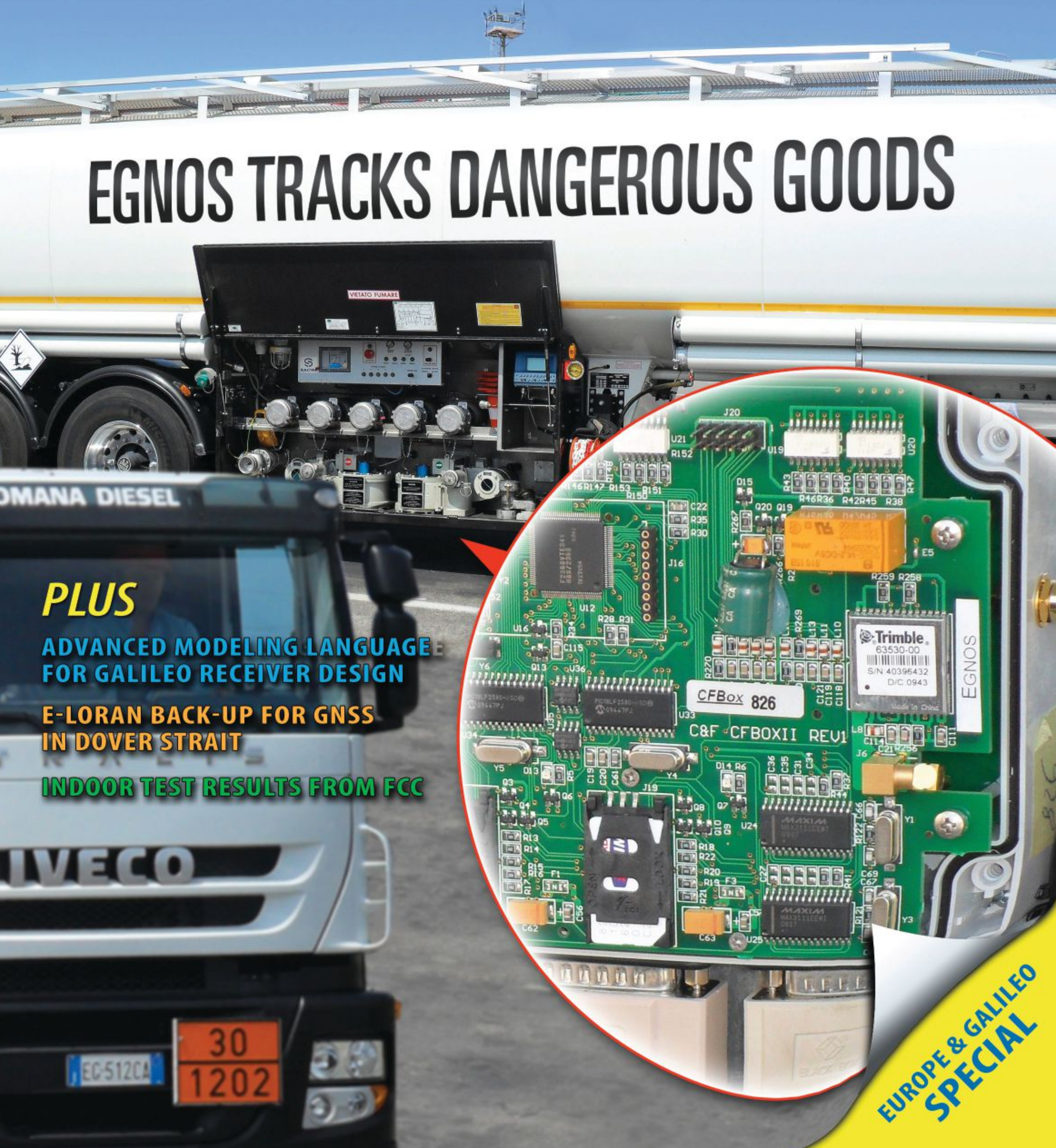

EGNOS TRACKS DANGEROUS GOODS

PLUS

ADVANCED MODELING LANGUAGE FOR GALILEO RECEIVER DESIGN

E-LORAN BACK-UP FOR GNSS IN DOVER STRAIT

INDOOR TEST RESULTS FROM FCC

EUROPE & GALILEO SPECIAL

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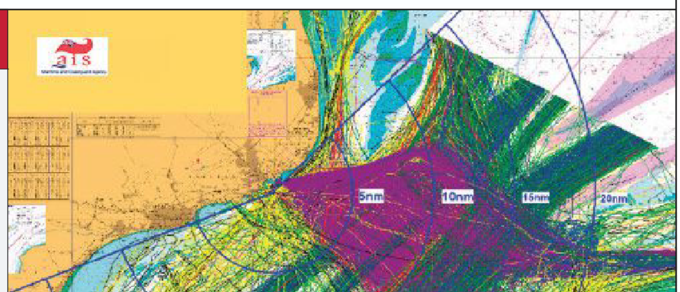

◀ Tanker, showing sensors installed on the chassies to record load status, and OBU on the tanker integrating a GPS/ EGNOS receiver.

EGNOS and Galileo Track Dangerous Goods

OS for Improved Accuracy, EDAS for Further Enhancement, Integrity Data

EGNOS availability over Europe, as a precursor of Galileo globally, provides a guaranteed level of positioning accuracy in real time, for tracking vehicles transporting hazardous material. The EGNOS Open Service enhances position accuracy compared to GPS-only. The EGNOS Data Access Service further enhances accuracy and indicates the quality of the position data received from GPS. As a result of the SCUTUM project, EGNOS is now used in the operational transport of dangerous goods by road in Europe.

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The road sector is among the largest markets for GNSS applications, not only in automotive mass-market but also in professional applications such as freight transport and logistics. Carrying goods by road naturally involves the risk of traffic accidents. If the goods are dangerous, there is also the risk of incidents, such as hazardous spills, fire, explosion, chemical burn, or environmental damage. The many different kinds of authorities and operators active in the field have safety as a primary concern and make continuous efforts in this regard. To ensure that such transport continues being profitable and logistically effective, emphasis is placed on the quality and condition of infrastructure, on transport safety, and on supervision and control.

Technology's role, particularly that of GNSS, is to provide the capability of supervision and surveillance, and thus enable better incident management and proactive prevention of accidents, while enhancing work. Use of GNSS combined with sensors and wireless devices has rapidly increased to enable continuous tracking and tracing services. GNSS-tracking devices installed on board vehicles ensure that the position, the date and time, the speed and the course, and any deviation with respect to a predefined path (coordinates and time) are transmitted automatically to a monitoring center. Combined with sensors, such devices send positioning information and the critical status parameters of the material (depending on the nature of the transported material and sensor type: identification of the goods/packaging, temperature, pressure, tampering or valve opening, and so on).

At the monitoring center, positions are displayed on digital maps, and regular data reports are processed for:

- continuous tracking and tracing,
- control of the shipment in a specified route (according to

the plan and authorized path),
- early warning/alarm when an anomaly condition is detected,
- recording and logging for a regular summary of reported incidents, and
- informing emergency-response forces for preparation of management arrangements and supporting emergency response plans.

These operations help reduce the possibility of human error during transport, prevent incidents, enforce regulations, and support law enforcement.

The European Geostationary Navigation Overlay Service (EGNOS), a satellite-based augmentation system (SBAS), augments the GPS signal over Europe and provides more precise positioning services. In addition, it gives users information on the reliability of the GPS signals (integrity data).

EGNOS is designed for safety-critical civil aviation operations. The characteristics of the EGNOS signal are compliant with Radio Technical Commission for Aeronautics Minimum Operational Performance Standards (RTCA MOPS) for airborne navigation equipment using the GPS augmented by SBAS. EGNOS also allows multimodal/land transport applications; however, EGNOS optimal use in these applications requires specific customizations for environments not compliant to MOPS.

The majority of receivers available on the market and integrated in operational devices are EGNOS-enabled. EGNOS provides two services suitable for multimodal/land transport applications:

- EGNOS Open Service (OS) is made available to users equipped with GPS/EGNOS receivers, via the satellites' Signal in Space (SiS).
- EGNOS Data Access Service (EDAS) consists of a server that gets the data directly from EGNOS and distributes it in real time to professional users via terrestrial networks, within guaranteed delay, security, and performance.

Software solutions and technologies capable of using EDAS and able to deliver added-value services for road applications have been developed in various European projects in the past several years, have been extensively proven in real life, and are presently ready for operational use. During the last seven years, capitalizing on the efforts of national/European projects and company investments, Telespazio has developed LoCation Server (LCS) navigation software based on a patented algorithm, suitable for combined use of EGNOS OS/EDAS in road applications. LCS makes use of EDAS to augment EGNOS OS performance by:

- improving the availability of EGNOS OS, since EGNOS SBAS corrections are made available to users through terrestrial networks and thus also in the cases of poor SiS visibility or complete absence;
- enhancing EGNOS OS position accuracy using the patented software navigation solution to implement EGNOS SBAS corrections; and
- processing EGNOS integrity information to compute the protection levels that give a qualification and a level of confidence in the position information. LCS is configured to output horizontal protection level (HPL) and vertical protection level (VPL).

Between October 2010 and November 2011, the European project SeCUring the EU GNSS adopTion in the dangeroUs Material transport (SCUTUM) conducted an extensive trial campaign in various road environments (urban and extra-urban) and real operation scenarios, to assess the performances of EGNOS OS and EDAS in comparison with GPS-only. SCUTUM trials were carried out with GPS/EGNOS receivers available on the market for automotive applications.

Analysis of the data collected during the trials shows that EGNOS OS enhances GPS position accuracy by 3 meters in road environments

▲ **FIGURE 1** Top: the green line indicates the reference trajectory; the position obtained by using EDAS with LCS (yellow dot) is more accurate with respect to the position obtained by using EGNOS OS (red dot) and the position obtained by using GPS only (blue dot). Bottom: A snapshot displaying the HPL computed by using EDAS with LCS.

(see **FIGURE 1**). EDAS via LCS enables improvements over EGNOS OS by increasing the availability of SBAS corrections, further enhancing GPS position accuracy. Moreover, it affords the possibility of qualifying and guaranteeing GPS position information by exploiting EGNOS integrity and computing the protection levels.

SCUTUM Goods Tracking

Funded by the European Commission and managed by the European GNSS Agency (GSA), SCUTUM is the European best practice for the operational adoption of EGNOS in the transport of dangerous goods. An Italian oil company, eni, has had the opportunity to prove EGNOS added value compared to GPS alone, and to validate the relevant operational benefits in terms of higher safety and efficiency. The company adopted EGNOS to track and trace its operational fleet transporting dangerous goods throughout Europe. At the end of SCUTUM's project timeline in November 2011, more than 300 eni tankers transporting hydrocarbon and chemical products in seven European countries were monitored with EGNOS. Today eni plans to gradually extend the use of EGNOS to the transport of chemicals and aviation products, and to further European countries.

The tankers (shown in the **OPENING PHOTOS**) are equipped with GPS/EGNOS tracking devices, consisting of a set of sensors installed on the trailer to record the status of the loads. The sensors are connected to an onboard unit (OBU) installed on the truck that integrates a GPS/EGNOS receiver configured to use EGNOS OS. The OBU collects measurements from the sensors, detects information on the vehicle's parameters, measures the GPS/EGNOS position, and sends this set of data via a GPRS link to a remote monitoring platform (the transport integrated platform, or TIP) enhanced by LCS to use EDAS. The TIP receives the data from LCS, that is, EGNOS positions (corrected by EGNOS OS if available or corrected by EDAS), the relevant HPL and VPL, and visualizes them as shown in **FIGURE 2**.

LCS for EDAS Services

LCS consists of several software modules, among them a module connecting to EDAS to get EGNOS data, and a module implementing the navigation solution by means of the Telespazio algorithm.

LCS makes use of EGNOS SBAS messages plus GPS ephemerides received in real time from EDAS (using Service Level 1), the positions (GPS or EGNOS OS positions when available) and time, and raw GPS measurements (code ranges) from the GPS/EGNOS receiver integrated in the OBU.

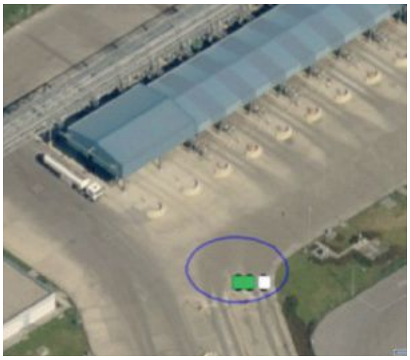
LCS calculates and returns EGNOS corrected positions (also in case of lack of SiS visibility) and the relevant protection levels obtained by processing the EGNOS integrity message. The HPL/VPL give a guarantee of the position information from the GPS/EGNOS receiver, as they qualify the reliability of position information and provide a measure of the confidence of the reliability.

If the position data from the OBU is not corrected with EGNOS OS (via the SiS), LCS uses the SBAS messages plus the GPS ephemerides, calculates and applies SBAS corrections, then calculates HPL/VPL. If the position data from the OBU is corrected with EGNOS OS (via the SiS), LCS returns only the HPL/VPL.

For remote monitoring of transported dangerous goods, the features provided by EDAS via LCS (better accuracy, higher confidence on the position, enhanced availability) are considered valuable by eni, as they enable tracking tankers more precisely and reliably along delivery routes, and also from bay to bay (**FIGURE 3**).

At the OBU, the positions are combined with other collected parameters, such as speed, engine parameters, driving parameters, loading/unloading the product on the vehicle, quantity of goods on the vehicle, product temperature and pressure, opening/closing bottom valves and manholes, opening/closing loading station. The information is sent to the TIP and visualized to the local operator, and also forwarded to the eni emergency room (shown in **FIGURE 4**) that is connected to the fire brigades and civil-protection emergency centers.

In an abnormal situation, such as the vehicle deviating from its planned path or being located in a dangerous/sensitive area, the local operator raises a warning and establishes a contact with the driver. If an accident occurs, an alarm is generated also at the eni emergency room responsible for emergency management and coordinating search-and-rescue operations with the proper public entities. The information is also used to keep the involved transport operator and eni's customers informed.



▲ **FIGURE 2** Operational tanker remotely monitored at the TIP by EDAS via LCS.

▲ **FIGURE 3** Accurate remote monitoring of a tanker in a bay area.

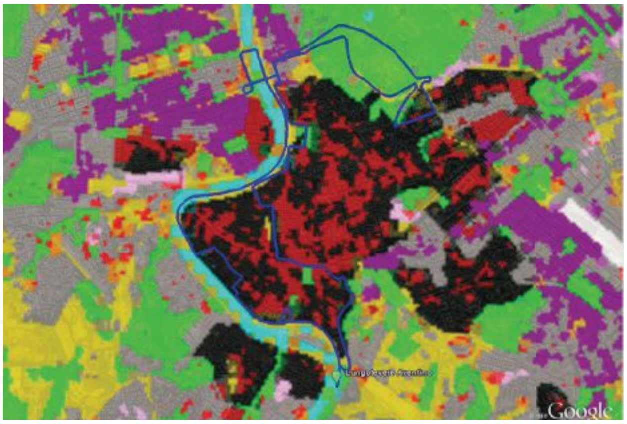
Additionally, this information is stored for law enforcement and prevention purposes. Position data and parameters are analyzed to produce statistics and study cases of near-miss accidents.

Benefits generated from EGNOS lie primarily in the capability to implement more accurate risk management and to strengthen safety and prevention. The higher precision with respect to GPS alone and the location achieved by using EDAS via LCS ensure more accurate and reliable monitoring of operations in normal and critical situations, and thus are valuable for commercial purposes and safety reasons. Moreover, eni considers the position guarantee given by the protection levels useful for research on accident prevention.

Multipath-Mitigation Algorithm

SCUTUM also implemented and tested a multipath-mitigation

▲ **FIGURE 4** eni emergency room.



▲ **FIGURE 5** Method for driving environment identification by means of a clutter map.

algorithm used to enhance LCS, to further mitigate the effects of code multipath, typical of land applications. Developed in cooperation with the University of Calgary, the algorithm is based on a fault detection and exclusion (FDE) method and is designed to ensure that biased/multipath-affected observations do not contaminate the navigation solution.

As SCUTUM deals with a road transport application, the assessment targeted the HPL only. The algorithm is based on a statistical-empirical concept combining:

- an FDE procedure using a statistical reliability method for the detection and removal of code-range observations corrupted by multipath; and
- a field-testing procedure using the receiver under study and a geodetic-quality receiver to produce a reference trajectory.

The FDE procedure consists of sequential steps:

- Computation of the navigation solution by means of a least-squares solution to obtain the calculated position, the HPL, and the residuals;
- Reliability testing on the residuals, to detect the outliers (observations that contain biases and thus are considered measurements affected by multipath errors);
- Exclusion of the detected outliers and re-computation of the navigation solution;
- Iteration of the steps. In each iteration, the observation with the largest residual flagged as an outliner is removed.

The procedure ends once no further outliers are isolated, or the number of remaining observations is less or equal to five, or several special-case conditions occur. Outlier detection is done on the basis of a rejection threshold on the standardized residual. This rejection threshold is a parameter of the multipath-mitigation algorithm and is tuned by means of the field-test results. Additionally the multipath-mitigation algorithm behavior is a function of other parameters that depend on various factors, including satellite elevation, signal strength, and overall satellite geometry.

Field Trials

SCUTUM field trials covered several environmental conditions and LCS configurations. Tests were performed in a wide range of Italian urban and extra-urban road environments. They considered five different typical driving environments (**TABLE 1**), corresponding to different levels of GPS and EGNOS signal availability and multipath, and various vehicle speeds and dynamic characteristics, with the objective of testing the robustness of LCS's navigation solution.

From a physical point of view, the presence of natural and/or artificial obstacles could lead to lack of GPS and SBAS signals, worse satellite geometry, and introduction of additional errors in the measurements due to multipath propagation effects. Urban canyons are particularly prone to such effects, although they occur also in other cases depending on the topographic characteristics of the environment. For these reasons, the trials covered all possible environments traveled by LCS users, to provide a complete technical and business analysis for each operational condition.

To accurately indentify the appropriate driving environment, trial paths were matched on clutter maps categorizing the different driving environments (as shown in **FIGURE 5** in the example of a trial path in Rome).

A reference trajectory, hereafter called the true path, was calculated in post-processing, through a kinematic differential GPS method, by using GPS L1 and L2 carrier-phase measurements, combined with inertial navigation system (INS) measurements.

The differential GPS L1 and L2 carrier measurements were collected with a reference receiver installed near each test location, at an inter-receiver distance not exceeding 20 kilometers. The reference receiver was geo-referenced via a dedicated GPS network solution (based on a continuous collection campaign of at least two days' data). The combination with INS targets smooth trajectories free from jumps, even in difficult GPS environments.

Scenario	Environment	Description		Speed & Dynamics
		Road Type	Details	
Urban	Urban 1	Deep Urban	Roads in downtown core flanked by high-rises	Limited speed. Frequent starts and stops
	Urban 2	Urban Thruway	Major Multilane roads with nearly constant 3-4 storey buildings and occasional higher buildings	Medium speed. Mainly free-flowing, occasional traffic jam
	Urban 3	Major Urban Roads / Local Roads	Suburban streets. Similar to urban thruways with lower density of buildings	Medium speed. Frequent starts and stops
Extra-urban	Extra-urban 1	Freeway / Motorway	Open-sky view and occasional overpass	High speed. Free-flowing, mainly straight
	Extra-urban 2	Rural Thruway / Major Extra-urban Roads	Rural road with occasional buildings	Medium speed. Free-flowing and mainly straight

▲ **TABLE 1** SCUTUM field trials driving environments.

▲ **FIGURE 6** GPS/INS system installed in the vehicle.

▲ **FIGURE 7** OBUs in test vehicle.

The tests ran on two identical OBUs, one GPS-only and one using GPS+EGNOS. The two OBUs and the GPS/INS system were installed in a test vehicle (**FIGURE 6**) and connected to a standard GPS patch antenna for automotive applications. Two pairs of OBUs were used (**FIGURE 7**).

Test Results

The trials collected these data sets:

- Raw measurements from the GPS/INS system;
- Positions and raw measurements from the two OBUs, GPS and GPS+EGNOS respectively.

As mentioned, positions and raw measurements from the GPS OBU were processed by LCS's navigation solution in three configurations:

- LCS baseline, running the baseline multipath mitigation method (based on the proprietary patented algorithm);
- LCS enhanced, applying the multipath-mitigation algorithm with default settings of several parameters;
- LCS enhanced and tuned, applying the multipath-mitigation algorithm with tuned parameters. The tuning was obtained by applying the combined statistical-empirical concept described earlier.

Data collected during the field trials was analyzed in terms of:

- average values for the horizontal navigation system error (HNSE) that is the horizontal difference of the OBU position with respect to the reference trajectory;
- average values for the HPL that gives an indication of the confidence/guarantee of the position above mentioned; and
- the availability of the processing of LCS's navigation solution.

Test data was analyzed with both commercial and freely available software packages. **TABLE 2** reports the performances of LCS in its baseline configuration for each driving environment. **TABLE 3** reports the performances of LCS by means of the multipath-mitigation algorithm with different tunings for extra-urban and urban environments.

The results show that for the road environments tested, LCS baseline performs better than statistical FDE.

From these results, an interesting conclusion can be drawn: in the road environments tested, a traditional FDE approach is not as effective as would be expected. Specifically, the removal of observations with large residuals resulted in larger overall position errors, both before and after attempting to estimate a larger observation variance than normally used for GPS. The reason for this is that in urban environments and extra-urban road environments there is significant multipath, corrupting many observations at the same time that the number of available observations is low. The conclusion is that on average, in the environments tests, it is better to leave small, but still statistically detectable errors in the solution than to remove them and degrade the solution geometry.

The fault-detection approach will be more appropriate in a multi-constellation GNSS, and in particular in the future when Galileo satellites can be used in conjunction with GPS, resulting approximately double the satellite availability in all environments.

TABLE 4 summarizes average performances for GPS+EDAS using LCS baseline compared with those of the GPS-only and GPS+EGNOS.

Workshop Agreement

SCUTUM also carried out a European Committee for Standardization (CEN) workshop that elaborated the CEN Workshop Agreement (CWA) 16390:2012, *Interface control*

Driving environment	GPS HNSE (m)	GPS+EGNOS OS HNSE (m)	GPS+EGNOS CS using "LCS baseline" HNSE (m)	GPS+EGNOS CS using "LCS baseline" HPL (m)	GPS+EGNOS CS using "LCS baseline" availability (%)
Urban 1	2.5	2.1	2.0	11.0	35.06
Urban 2	2.2	1.8	1.6	10.0	62.16
Urban 3	2.2	2.0	1.9	10.2	66.81
Extra-urban 1	1.4	1.0	1.0	9.6	85.68
Extra-urban 2	3.4	2.1	1.2	9.0	92.39

▲ **TABLE 2** Performances of LCS baseline for driving environments.

Driving environment	GPS+EGNOS CS using "LCS baseline (with no FDE algorithm)"		GPS+EGNOS CS using "LCS enhanced with default FDE algorithm"		GPS+EGNOS CS using "LCS enhanced with tuned FDE algorithm"	
	HNSE (m)	HPL (m)	HNSE (m)	HPL (m)	HNSE (m)	HPL (m)
Urban	2.1	10.1	4.7	12.5	4.5	11.8
Extra-urban	1.2	9.0	4.6	13.2	4.1	11.6

▲ **TABLE 3** Performances of LCS enhanced by multipath mitigation algorithm with different tunings.

Driving environment	GPS HNSE (m)	GPS+EGNOS OS HNSE (m)	GPS+EGNOS CS using "LCS baseline" HNSE (m)	GPS+EGNOS CS using "LCS baseline" HPL (m)	GPS+EGNOS using "LCS baseline" availability (%)
Urban	2.2	1.9	2.1	10.1	56.56
Extra-urban	3.3	2.0	1.2	9.0	92.11
All environments	2.6	1.9	1.7	9.6	64.69

▲ **TABLE 4** Average performances of GPS+EDAS by means of "LCS baseline" in comparison with GPS-only and GPS+EGNOS OS.

document for provision of EDAS-based services for tracking and tracing of the transport of goods, that is, the technical specification for development of EDAS-based products and applications.

CWA 16390 specifies:

- the data (and relevant format) needed from the GPS/EGNOS receivers by the software solutions connected to EDAS, to enable the implementation of products and added value services; and
- the type/format of the added value services produced by the software solutions (EDAS-based services).

The technical specification defined in CWA 16390 is architecture/technology-independent and flexible, so as to:

- cope with different architectures (for example, those envisaging software solutions running in the monitoring platforms or in the OBUs); and
- ensure its applicability in ITS systems and various mobility applications.

CWA 16390 was endorsed by several European stakeholders from industry, institutions, and the research sector. The Ministries of Transport in Italy and France, partners in the SCUTUM project, validated it as part of a shared vision for EGNOS adoption and exploitation. Italy's Ministry of Transport is presently carrying out the possible evolution of CWA 16390 into an Italian standard.

Conclusions

SCUTUM represents the first step towards a larger use of EGNOS in Europe for the provision of services for road applications, and opens the market for Galileo. Its key findings are that EGNOS OS generally enhances the position measured using GPS-only in all extra-urban and urban environments. EDAS generally provides further enhancements, and also gives an indication of the quality of the position data received from the GPS.

LCS is a plug-in solution that enables easy retrofitting of existing GPS systems to use EGNOS, but optimized for road applications. By integrating it in tracking and tracing monitoring platforms and configuring the vehicle-installed OBUs, LCS enhances GPS position accuracy by approximately 4 meters and provides a level of confidence in the position information in the form of an HPL and a VPL. LCS will also improve GPS/Galileo integrated solutions when Galileo is operational. Its navigation solution will be more robust with Galileo and in general with multiple constellations, thanks to the availability of more satellites in view.

Manufacturers

A **NovAtel** *FLEXG2-V2-L1L2* served as GPS reference with a NovAtel (*www.novatel.com*) dual-frequency *GPS-702GG* antenna. An **Oxford Technical Solutions** *RT2002* dual-frequency GPS/INS system (*www.oxts.com*) served as rover. The two OBUs integrated a **u-blox***5* GPS/EGNOS receiver (*www.u-blox.com*). In its present configuration, LCS is connected to a dedicated GPS/EGNOS receiver, NovAtel *ProPak-V3-L1* acting as EDAS back-up for robustness reasons.

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