

# Satellite and Terrestrial Radionavigation Systems on European Inland Waterways

**J. Januszewski**

*Gdynia Maritime University, Gdynia, Poland*

**ABSTRACT:** The usefulness for all sea users of Satellite Navigation Systems (SNS), Satellite Based Augmentation Systems (SBAS) and Automatic Identification System (AIS) is well known. The possibility, actual and future, of the utilization of all these systems on European inland waterways, GPS augmented by IALA DGPS reference stations, GPS augmented by European SBAS – EGNOS from direct Signal-in-Space (SIS) and GPS augmented by EGNOS from re-transmission over AIS, is presented in this paper. The operational systems, such as the German network IALA DGPS and DoRIS, and planned system such as GALEWAT, MARGAL, MUTIS and MARUSE are described also.

## 1 INTRODUCTION

The European Union recognises the great potential of inland navigation as an alternative transport mode for freight transport. Facing tremendous capacity and environmental problems in the land transport modes, in particular road transport, the European transport policy consequently has a great interest in developing inland waterway transport to become a real alternative whilst keeping the environmental burden to a minimum [www.iris-europe.net].

The continuous information of user's position is one of the most important factors, which determines the safety of the user in the transport, on inland waterways also. The requirements towards radionavigation are well defined for the maritime world (sea navigation, coastal navigation etc.) in the IMO (International Maritime Organization) resolution A.915(22). As the IMO is not responsible for inland waterways, and these requirements are not binding, the new performance requirements must be created. The most comprehensive approach for the inland navigation community is the project MARUSE. For traffic management and information the following requirements have been identified: absolute accuracy – 3 m, alert limit – 7.5 m, time to alarm – 10 s, integrity risk (per 3 hours)  $-10^{-5}$ , availability (% per 30 days) – 99.8, continuity (%/3hours) – 99.97 [Amlacher et al. 2007]. The accuracy requirement of 3 m has been confirmed in real time operations, e.g. for the matching of the radar image with the Electronic Navigation Chart (ENC).

Moreover the coordinates of actual position must be sent to other ship's devices and different kind of land stations. That's why the user's position on inland waterways must be fixed continuously by specialized electronic position-fixing systems – satellite navigation systems (SNS), the differential mode of these systems, satellite based augmentation systems (SBAS) and terrestrial radionavigation systems [Januszewski J. 2007].

## 2 SATELLITE NAVIGATION SYSTEMS AND THEIR DIFFERENTIAL MODE

A presently (December 2008) unique, fully operational and global system is the American GPS (Global Positioning System – Navstar) and its differential mode DGPS. Experience has shown that stand alone GPS system does not provide sufficient accuracy for a reliable operation of the system. Many maritime administrations have implemented a DGPS service in their waters to improve safety and efficiency of navigation [Hoppe M. et al. 2005]. At present more than 300 DGPS reference stations have operational status; and this number is still increasing [ALRS 2008/09]. In this paper these stations are called IALA DGPS.

For maritime users (channel and coastal navigation, harbour approach) the IALA DGPS stations are situated at seashore, for inland navigation the additional stations must be installed inland in properly chosen places.

The provision of DGPS corrections can be realized in two different ways:

- IALA DGPS network covering all inland waterways of the chosen region or the territory of the country,
- the distribution of the DGPS corrections via AIS base stations.

The first solution became realized in Germany. The two IALA DGPS stations were located in Helgoland and in Gross Mohrdorf, which cover the German Bight and the German part of the Baltic Sea, respectively. These stations and the third, planned in Zeven, will provide good coverage of the harbour entrances of the great three German rivers – Elbe, Ems and Weser. This IALA DGPS stations network became extended for four stations – Bad Abbach (Bavaria), Iffezheim (Baden-Württemberg), Koblenz (Rhineland-Palatinate) and Mauken (Sachsen-Anhalt), which permitted coverage for all of Germany. The range of these stations over land is approximately 250 km [Hoppe M. et al. 2005].

The second solution became realized in Austria, via the DoRIS (Donau River Information Services) system. 23 DoRIS base stations are installed along the Danube, two of them are augmented with DGPS functionality and distribute the corrections over the neighbouring base stations to the users onboard ships. The distribution of these two stations, called AIS DGPS, is such that the distance between the user and the nearest DoRIS station is less than 90

km always. The AIS DGPS stations produce the AIS message type 17, according to the ITU-R M.1371-1 standard, which includes the DGPS correction data. Over the AIS radio data channel this message is broadcast every 10 seconds. The DoRIS system has been operational since 2006 year with no major outages.

Nowadays the GLONASS (Russian system) cannot be a continuous position fixing system (the number of operational satellites is less than nominal 24 continually). The new system – Galileo, sponsored by the European Union, is under construction as the European contribution to the next generation of satellite navigation [Spaans J. 2008], but these two systems are already taken into account, in this paper also. The new navigation satellite system (NSS) actually built by China, called Compass, was not taken into account.

The number of satellite (ls) which can be used for to fix ship's position first of all depends on masking elevation angle  $H_{\min}$  of the receiver and the number of satellites fully operational at given moment. If the angle  $H_{\min}$  increases, the number ls decreases. As the most important European inland waterways are at geographical latitudes 40–60°N, we can pose the question – what is or what will be the geometry (elevation angle and satellite azimuth, in particular) of two the most important SNSs – GPS and Galileo in this part of Europe.

Table 1. Distribution (in per cent) of satellite elevation angles (H) in open area for Galileo system (GAL) and GPS system (GPS) at different observer's latitudes ( $\varphi$ )

$\varphi$ [°]	System	Elevation angle H [°]								
		0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
40-50	GAL	23.0	16.7	14.3	11.8	9.9	8.5	7.6	6.1	2.1
	GPS	22.2	16.9	14.9	12.1	10.1	8.7	7.2	5.8	2.1
50-60	GAL	23.0	19.7	14.5	11.8	9.3	8.2	6.4	4.8	2.3
	GPS	24.1	19.3	14.8	11.3	10.1	7.8	6.1	4.1	2.4

Table 2. Distribution (in per cent) of satellite azimuths for different masking elevation angles ( $H_{\min}$ ) for Galileo system (GAL) and GPS system (GPS) at different observer's latitudes ( $\varphi$ )

$\varphi$ [°]	$H_{\min}$ [°]	System	Satellite azimuth H [°]							
			0–45	45–90	90–135	135–180	180–225	225–270	270–315	315–360
0		GAL	8.7	19.5	11.1	10.8	11.1	11.1	19.0	8.7
		GPS	7.1	20.3	11.3	11.0	11.0	11.9	20.0	7.4
40-50	5	GAL	7.0	20.7	11.4	10.8	11.4	11.4	20.4	6.9
		GPS	5.6	21.3	11.6	11.1	11.0	12.4	21.4	5.6
	15	GAL	4.6	22.4	11.7	10.7	11.6	11.8	22.2	5.0
		GPS	3.4	22.7	12.1	11.2	10.8	12.7	23.6	3.5
50-60	0	GAL	10.0	17.4	12.0	10.4	11.1	12.1	17.1	9.9
		GPS	8.9	17.6	12.3	11.1	11.1	12.4	17.3	9.3
	5	GAL	8.6	18.2	12.3	10.5	11.4	12.6	17.8	8.6
		GPS	7.1	18.5	13.0	11.4	11.4	13.0	18.3	7.3
	15	GAL	4.0	20.7	13.6	11.4	12.2	14.1	20.3	3.7
		GPS	2.7	20.3	14.6	12.2	12.3	14.3	20.9	2.7

The distribution (in per cent) of satellite elevation angles (H) in two latitude zones, 40–50°N and 50–60°N (containing mentioned above waterways) for both systems is presented in the Table 1. We recapitulate that:

- the distributions of angle H values in all zones for both systems are practically the same,
- for both systems in all zones about half of satellites are visible below 30°, while the percentage of satellites visible above 70° is less than 10.

The distribution (in per cent) of satellite azimuths for masking angle  $H_{\min} = 0^\circ$ ,  $H_{\min} = 5^\circ$  and  $H_{\min} = 15^\circ$  for both systems at different observer's latitudes is shown in the Table 2. We can say:

- distributions of satellite azimuths for both systems are practically the same at given angle  $H_{\min}$ ,
- the number of satellites in different azimuth's intervals depends on the observer's latitudes for both systems,
- at latitudes 40° to 60°, independently of  $H_{\min}$ , the number of satellites with azimuth from interval 315–045° are for both systems less than from intervals 045–090° and 270–315° considerably.

It means that position accuracy depends on river or canal orientation and the form of shoreline. The distributions in the tables 1 and 2 are the results of the calculations made by using author's simulating program. The detailed results were presented among other things in [Januszewski J. 2004] and [Januszewski J. 2005].

Nowadays on inland waterways the 3D position nevertheless can be obtained in almost all cases, because the GPS spatial segment consists of 31 satellites fully operational.

### 3 SATELLITE BASED AUGMENTATION SYSTEMS

The Satellite Based Augmentation Systems (SBAS) as Wide Area Augmentation System (WAAS), Multi-functional Transport Satellite Based Augmentation System (MSAS) and European Geostationary Navigation Overlay System (EGNOS) are adequately accessible in USA, Canada, Japan and Europe [Prasad R., Ruggieri M. 2005]. The C/A codes used by all these systems belong to the same family of 1,023-bit Gold codes as the 37 PRN codes reserved by the GPS system.

The EGNOS system will provide three services:

- open service (free access but without guarantee),
- commercial data distribution (with guaranteed service),

- safety of life (almost real time integrity), and this service will be the most interesting for all users of European inland waterways, certainly.

The EGNOS user segment is composed of a GPS and/or GLONASS receiver and EGNOS receiver. The two receivers are usually embedded in the same user terminal. As the receiver can process the message in a 6-second duty cycle the integrity time to alarm is limited to the duty cycle time.

EGNOS will be fully operational in April 2009; it is designed for a wide number of applications, including transport on inland waterways. For the users of European inland waterways the problem of the visibility appears in the EGNOS system owing to the three geostationary satellites (GEO) – two operational: Inmarsat-3-F2 Atlantic Ocean Region-East (AOR-E) and Inmarsat-3-F5 Indian Ocean Region-West (IOR-W) located at longitudes 015.5°W and 025°E, respectively and one with status industry test transmissions – Artemis at 021.5°E. The 3 current EGNOS C/A codes are 120, 126 and 124 respectively [Kaplan, E.D., Hegarty, C.J. 2006].

Due to the environment along the shoreline of the rivers/canals, the risk of losing line-of-sight to GEO satellites is quite high. Obstacles could be mountainous terrain, high buildings, big bridges, or other technical structures (e.g. harbour area, locks).

### 4 TERRESTRIAL RADIONAVIGATION SYSTEMS

Terrestrial radionavigation system Loran C (Long Range Navigation) is a low frequency electronic position fixing system using pulsed transmissions at 100 kHz. Groundwave ranges of from 800 to 1200 n miles are typical, depending upon transmitter power, receiver sensitivity, and attenuation over the signal path.

On European inland waterways two Loran C chains (6731 and 7499) can be used with three lines of positions: 6731-X, 6731-Z and 7499-X in France and northwest Germany, in particular. As the location of all European Loran C System (Ex-NELS) transmitters are designed for the sea user (Norway Sea and North Sea) first of all, this system cannot be taken into account in the navigation on great European rivers such as the Rhine and Danube.

Eurofix is an integrated radionavigation and communication system, which combines Loran C and DGPS by sending differential satellite corrections to users as time, modulated signal information. At present four Ex-NELS, Boe and Vaerlandet (Norway), Sylt (Germany), Lessay (France), stations transmit Eurofix corrections only,

additionally the number of user's receivers is very small. That's why this system cannot be used on inland waterways.

## 5 AUTOMATIC IDENTIFICATION SYSTEM

Automatic Identification System (AIS) is a ship borne radio data system continuously broadcasting ship identification number (ID), its position, course and speed, and other data to all nearby ships and to shore side infrastructure on a common VHF radio channel. On inland waterways, the data transmission is based on the "Vessel Tracking and Tracing Standard for Inland Navigation" published by the Central Commission for the Navigation on the Rhine (CCNR) and by the European Commission in 2007. This standard describes the so called "Inland AIS" which guarantees 100% compatibility with the maritime AIS system while extending AIS to the needs of inland waterway transportation [Amlacher C. et al. 2007].

Inland ships, which are equipped with AIS, can utilize the information transmitted from other ships by AIS to improve the traffic image surrounding a traffic situation.

We can distinguish two different applications of AIS in inland navigation:

- for navigation support on board,
- for traffic information and traffic management services.

The AIS transponder as a key element for RIS needs to be installed onboard ships, as well as in base stations on shore. A transponder unit generally comprises three main functional elements, of which one is a Global Navigation Satellite System (GNSS) module with the capability of applying differential GPS or EGNOS corrections to the measurements [Trögl J. et al. 2004].

Based on the data of AIS exchange, the visualization of traffic information on an ENC, so called Tactical Traffic Image (TTI) is enabled. This TTI supports the skipper in his nautical maneuvers.

## 6 INTEGRATED SYSTEMS

Accuracy of the ship's position is a functional requirement for inland waterways operations. However without integrity information the data received from GPS system and/or DGPS system can only be used with restrictions. Integrity is the ability to provide users with warnings within a specified time when the system should not be used for navigation. Although this may be acceptable for some users, it is not acceptable for other users.

The provision of integrity information by the GPS constellation is however not foreseen in the near future, because only the next generation's satellites block III is expected to provide, among other things, a system integrity solution. Satellites of the nearest block IIF will be without integrity. Therefore, the need of integrity is evident. Nowadays this kind of information can be obtained from EGNOS, and in the future from Galileo. That's why information about the position and integrity can be assured by the integrated systems with these two systems mentioned above.

A discussion of the usefulness of Galileo system for the inland waterways two planned services, Open (OS) and Safety of Life (Sol), will be very interesting for the users. Galileo will provide increased performance through the use of dual (L1 + E5a) or triple (L1 + E5a + E5b) frequency observations as well as improvements in safety through the provision of an integrity message.

– The five possible integrated systems and their most important parameters are presented in the Table 3. Let us discuss each parameter:

- GPS integrity. As this integrity is assured by the system EGNOS, it takes place for all integrated systems, except the combination GPS/Galileo,
- Galileo integrity. It is assured by all integrated systems in which one of the systems is Galileo,
- improved RAIM (Receiver Autonomous Integrity Monitoring); as above,
- redundant system; as above,
- redundant augmentation. It is assured by these systems, in which the EGNOS corrections reach the user's receiver through AIS,
- system failure tolerance. It is assured by all integrated systems in which one of the systems is Galileo,
- robustness to interference; as above.

AIS DGPS provision is fully operational in Austria, Slovakia has a pilot system in operation and Bulgaria, Croatia, France, Hungary, Romania, Serbia and Ukraine are currently preparing implementation of similar systems [Amlacher C., Trögl J. 2008].

Several projects utilizing NSS, SBAS and AIS in RIS are already realized in Europe with several more prepared as follows.

### 6.1 GALEWAT project

The GALEWAT (Galileo and EGNOS for Waterway Transport) project, founded by the European Space Agency (ESA) Advanced Research Telecommunications program ARTE-5, aims the realization of a first step towards the introduction of EGNOS and finally Galileo into the upcoming River Information Services (RIS) all across Europe.

Table 3. The integrated systems and their parameters.

Systems	GPS Integrity	Galileo Integrity	Improved RAIM	Redundant System	Redundant Augmentation	System Failure Tolerance	Robustness to Interference
GPS, EGNOS SIS	✓						
GPS, EGNOS SIS, EGNOS through AIS	✓				✓		
GPS, Galileo		✓	✓	✓		✓	✓
GPS, Galileo, EGNOS SIS	✓	✓	✓	✓		✓	✓
GPS, Galileo, EGNOS SIS, EGNOS through AIS	✓	✓	✓	✓	✓	✓	✓

Among others, the following topics are subject to the GALEWAT project [Abwerzger C. et al. 2005]:

- identification of user requirements related to AIS and EGNOS service parameters for transport efficiency, waterway transport in particular,
- replacement of conventional RIS local differential GPS stations by direct reception of the EGNOS signal in shipboard transponders,
- bridging outages of the EGNOS SIS by retransmitting the EGNOS differential corrections and integrity data via AIS base stations in areas without direct EGNOS reception,
- analysis and validation of EGNOS, integrated into the AIS transponder concept, being capable to meet the user and service requirements.

The GALEWAT is composed of five segments:

- ship, several ships, all equipped with standard equipment (AIS transponders with GPS and DGPS receivers), one additionally with extended equipment which allows the position fixes in different modes (GPS stand alone, GPS + IALA DGPS, GPS + EGNOS SIS, GPS + EGNOS AIS),
- shore, mainly comprises two AIS base stations which must receive the EGNOS signal (with the differential corrections) from GEO satellites and then broadcast re-formatted EGNOS information via the AIS data link,
- regional, terminals located nearby strategic points, which are connected to several shore elements to gather tactical traffic information of the area,
- operator, e.g. national control center storing all traffic information provided by RIS in a large database,
- external, which consists fundamentally of web interface where external users can retrieve relevant traffic information of the area.

The public demonstrations of this system in Vienna (Austria), Lisbon (Portugal) and Constanta (Romania) have already been successfully executed.

### 6.2 MARGAL project

The MARGAL project, prepared by Kongsberg Seatex (Norway) and eight European concerns, is based on AIS technology to monitor vessels and to

deliver EGNOS differential corrections and integrity warning to applications where direct reception signal is not possible [Kristiansen K. et al. 2005].

This project is a harmonized and seamless solution for maritime navigation for European ports and inland waterways. The project MARGAL has shown that changes to the actual version (2.3) of RTCM message format and to the AIS handling of message 17 (RTCM message) are needed to meet, respectively, the accuracy requirements for new services and the time to alarm requirements. The current EGNOS and the future Galileo integrity services can be utilized in operational applications like remote pilotage and queue systems for ports and locks [www.margal.net].

### 6.3 MUTIS project

MUTIS (Multimodal Traffic Information Services) is a project within the ARTES (Advanced Research in Telecommunications Systems) 3 program of ESA. This project is aiming at the study of the feasibility of the introduction of satellite based communication LEO (Low Earth Orbit) into the upcoming RIS across Europe [Trögl J. et al. 2004].

The demonstration within MUTIS will focus in the Danube waterway from Vienna in Austria to Constantia in Romania on the length of approximately 1700 km. A vessel is equipped with necessary facilities as EGNOS receiver, PC and LEO & GSM communication. In this way the vessel transmits every 15 minutes own position obtained from GPS system and EGNOS system over a LEO service provider to database & control station. Position information and data from/to the vessel will be transmitted to/from this station via several channels:

- GSM as a terrestrial wireless system,
- GLOBALSTAR as “big LEO” satellites system,
- IRIDIUM as alone satellite system,
- THURAYA as a low-cost GEO satellite system.

### 6.4 MARUSE project

The MARUSE project, part of the EU 6<sup>th</sup> framework programme, was realized in the years 2005–2007. The main objective of this project is to demonstrate

Galileo differentiators and the benefits of using Galileo and EGNOS in maritime and inland waterways applications. The technology development consists of two major elements: a user terminal and a local infrastructure [www.maruse.org].

One of four demonstrations took place at the Danube Iron Gate I (two locks) in Serbia in June 2007. GPS differential corrections are transmitted via the AIS data link (AIS Msg.17). The vessel is equipped with a Maritime User Terminal utilizing a standard AIS transponder augmented by a GPS/GLONASS positioning element and a digital compass for a determination of vessel heading. The AIS transponder system is linked to an ECDIS viewer providing the skipper with the TTI and the integrity information. In the future the vessel's position will be fixed by a third NSS – Galileo [Christiansen S.E. et al. 2007].

## 7 CONCLUSIONS

- the measurements realized within the framework of several European projects showed the full usefulness of SNS, SBAS and AIS on inland waterways, particularly the great European rivers Rhine and Danube,
- as the distribution of satellite azimuths of each SNS depends on observer's latitude, the position accuracy of the ship sailing with high river coast on both sides depends on its geographic location also,
- the results obtained from measurements using EGNOS signals (GALEWAT project) showed that GPS augmented by EGNOS from SIS can be a good candidate for inland waterway safety-critical applications with required accuracy below 10 m, high system availability, and protection level below 25 m,
- the use of AIS to broadcast EGNOS data (GALEWAT project) is not introducing any significant degradation of performance compared to the EGNOS performance directly obtained with the SIS (DoRIS project),
- IALA DGPS reference stations situated today at seashore first of all can be installed and used inland, e.g. four stations already installed in Germany,

- the actual projects, e.g. MARGAL, MARUSE, include the implementation of software defined vessel's receivers making a smooth transition from EGNOS to Galileo possible,
- integrity of the systems built around and the needs of inland navigation can be assured by these integrated systems only, one of which is the present EGNOS system, and in the future Galileo system also.

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