EGNOS; satellite systems; transport

Radosław FELLNER
Civil Aviation Personnel Education Centre of Central and Eastern Europe
Krasińskiego 13, 40-019 Katowice, Poland
Corresponding author. E-mail: rfellner@wp.pl

ANALYSIS OF THE EGNOS/GNSS PARAMETERS IN SELECTED ASPECTS OF POLISH TRANSPORT

Summary. The transport sector requires efficient and accurate traffic management systems in airspace, on land and at sea. European Geostationary Navigation Overlay Service (EGNOS) may be part of these systems. However admission to its use in Poland requires analysis whether it fulfil international standards. This paper presents such verification of the EGNOS usefulness for: air, sea, road and rail Polish transport. Therefore, conducted a characterization and analysis of four parameters of the signal (accuracy, integrity, continuity and availability) based on data from the EGNOS Data Collection Network in the years 2011-2012. Monitored parameters were compared with current international requirements for the signals of satellite systems in force in the various types of transport. This allowed to determine whether the EGNOS system can be used in them.

ANALIZA PARAMETRÓW SYSTEMU EGNOS/GNSS W WYBRANYCH ASPEKTACH POLSKIEGO TRANSPORTU

Streszczenie. Sektor transportu wymaga efektywnych i dokładnych systemów zarządzania ruchem w przestrzeni powietrznej, na lądzie i morzu. Europejski Satelitarny System Wspomagania (EGNOS) może być ich częścią. Jednak dopuszczenie do jego wykorzystania w Polsce wymaga uprzedniej analizy pod względem spełniania międzynarodowych standardów. Niniejszy artykuł przedstawia taką weryfikację przydatności systemu EGNOS na potrzeby polskiego transportu: lotniczego, morskiego, klejowego i drogowego. W tym celu scharakteryzowano i przeanalizowano cztery parametry sygnału systemu (dokładności, wiarygodności, ciągłości i dostępności) na podstawie danych pochodzących z bazy danych EGNOS Data Collection Network z lat 2011-2012. Monitorowane parametry zostały następnie porównane z obowiązującymi międzynarodowymi wymaganiami dla sygnałów systemów satelitarnych w poszczególnych rodzajach transportu. Pozwoliło to na ustalenie, czy system EGNOS może być w nich wykorzystywany.

1. INTRODUCTION

Developing Polish transport services sector requires more effective traffic management systems in the sky, on land and at sea. Very often they use navigation satellite systems, which significantly improve safety of transported people and goods and help to optimize exploitation of vehicles, which brings economic benefits. It is estimated that 6-7% of European GDP depends on the use of satellite navigation and satellite technology and its market is worth 124 billion euro [1]. By 2020, this value is expected to rise to 250 billion euros. Satellite navigation is a catalyst for innovation and creates employment in many sectors of the economy. Over the next 20 years in Poland, employment directly and indirectly generated by air transport will reach 720 000 jobs.

Each satellite system must fulfill a number of well-defined parameters, which ensure reliability of the system and its full functionality. This article shows an analysis of performances of the European Geostationary Navigation Overlay Service (EGNOS) in terms of the criteria in selected aspects of Polish transport.

2. EGNOS/GNSS ARCHITECTURE

Whereas the Global Navigation Satellite Systems (GNSS) like American GPS and Russian GLONASS does not fully meet with the needs of the European market in terms of reliability and availability of services, as well as to end dependence on these military systems [11 - 13], European Union has decided to build its own satellite systems: Galileo and EGNOS [17]. Since the release in October 2009, EGNOS has been tested and passed the necessary certification. As a result in 2011 received the status of "Safety of Life", which confirms the safe use of the system, especially in aviation. At the same time EU declared to make Galileo operational in 2014 [2].

Although the use of EGNOS in air and sea navigation is very popular, in road and rail transport is not. Undoubtedly, it is the result of an insufficient number of experts in satellite navigation, who could implement new technologies in life, as well as lack of awareness of business owners about the benefits of using free satellite services. Entrepreneurs forget that these satellite systems improve: transportation management and emergency services in the EU, border security and EU peace-keeping missions. EGNOS also provides data about reliability of the GPS signal, giving an alarm within 6 seconds in case of faulty positioning information [3]. Moreover, risk of error was set at 1 to 10 million.

These results largely depend on the architecture of EGNOS, which is based on the following six components [4]:

1. 3 geostationary satellites (GEO): PRN 120 and PRN 126 operated by International Maritime Satellite Communication Organization (INMARSAT) and PRN 124 operated by European Space Agency (ESA); high precision of signals is provided by onboard atomic clocks;
2. 36 Ranging and Integrity Monitoring Stations (RIMS) located in Europe, North Africa, Canada, South Africa and South America; one of the station is located in the Space Research Centre of the Polish Academy of Sciences, the next closest is located in Berlin and Sofia; stations record the signals transmitted by the GPS, GLONASS and GEO satellites and send them to the Mission Control Centers (MCC);
3. 4 MCC contains Central Processing Facility (CPF), which uses the data received from the network of RIMS stations to elaborate clock corrections for each GPS satellite and elaborate a model for ionospheric errors over the EGNOS service area in order to compensate for ionospheric perturbations to the navigation signals;
4. 6 Navigation Land Earth Stations (NLES), two for each GEO satellites, transmit the EGNOS message received by the CPF to the GEO satellites for broadcast to users and to ensure the synchronization with the GPS signal; the station are located in: Torrejon (Spain), Fucino (Italy), Aussaguel (France), Raisting (Germany), Goonhilly (Great Britain), Sintra (Portugal);
5. EGNOS Wide Area Communications Network (EWAN), which is responsible for communication between all elements of the ground segment of the system;
6. Performance Access Check out Facility (PACF), which is responsible for trouble-free operation and functioning of the system.

RIMS, MCC, NLES and support facilities, which compose EGNOS ground segment, are presented in Fig. 1.

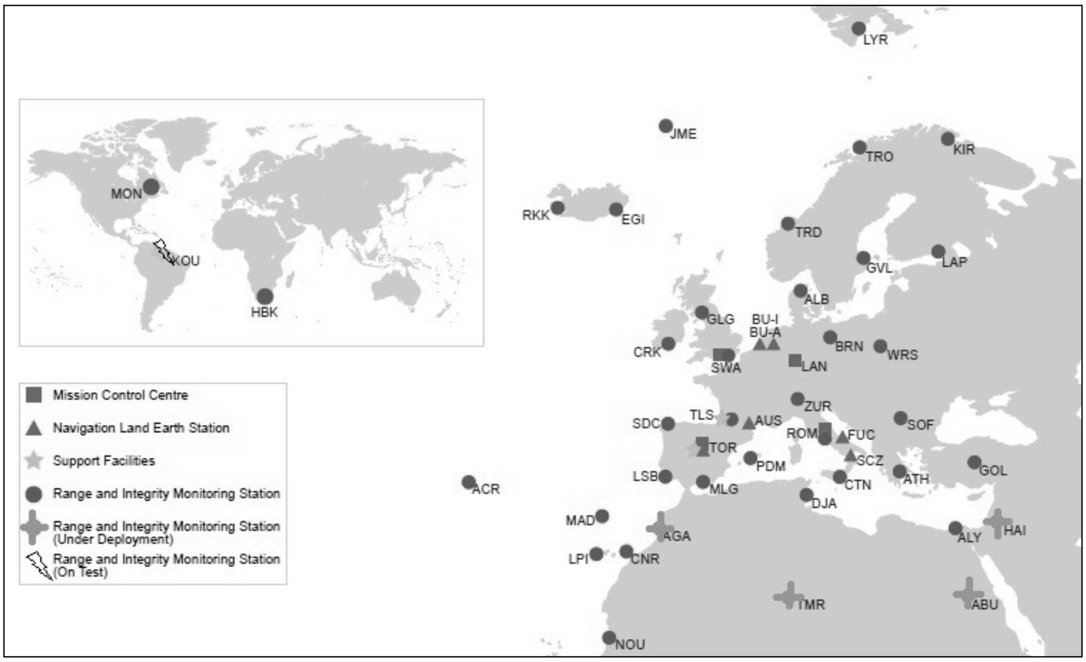


Fig. 1. EGNOS ground segment [4]
Rys. 1. Segment naziemny EGNOS [4]

Properly designed structure of the system is only one aspect determining the reliability of EGNOS. The next are four well-defined by International Civil Aviation Organization (ICAO) performances, which allow to verify usefulness of the system. These performances are [16]:

- Accuracy – the GNSS position error is the difference between the estimated position and the actual position. The question of accuracy considered in a number of articles [15]. According to the ICAO Standards and Recommended Practices (SARPs), at least 95% of the samples should be within the accuracy requirements for the given operation. The requirements for "Safety of Life" service are fixed at 16 m in the horizontal plane and 20 m in the vertical. EGNOS is currently available over its service area for 99% of the time;
- Integrity - is a measure of the trust that can be placed in the correctness of the information supplied by the total system. The EGNOS integrity requirements include both an alert limit in horizontal and vertical dimensions and an allocated time to warn the user (Time To Alert) corresponding to the intended level of service. Integrity risk shall be less than $2x10^{-7}$ with time to alert of 10 seconds;
- Continuity - is defined as the probability that the accuracy and integrity requirements will be supported by the navigation system throughout a flight operation or flight hour given that they are supported at the beginning of the flight phase and that the flight operation is initiated and predicated to be supported all along the flight. Continuity risk limit shall be less than 10^{-4}, $5x10^{-4}$ or 10^{-3} (it depends of the kind of approach);
- Availability - is the probability that the positioning service and the integrity monitoring service are available and provide the required accuracy, integrity and continuity performances. Availability is computed, at any point within the service volume, as the percentage of the time during which the service is available over the lifetime of the system, taking into account all the outages whatever their origins. The service will be declared available when accuracy, integrity and continuity requirements are estimated to be met.

Performances are gathering in EGNOS Data Collection Network.

3. PERFORMANCE ANALYSIS

Analysis of the continuity, accuracy, availability and reliability was conducted on the data from the EGNOS Data Collection Network gathered in 2011-2012 [5].

3.1. Accuracy

In the analyzed period, the accuracy of the EGNOS signal was in the range 1,1-1,7 m for horizontal positions and 1-1,3 m for vertical positions. The lower accuracy level was recorded in the autumn and winter. As shown in Fig. 2 precise measurements are possible in spring and summer.

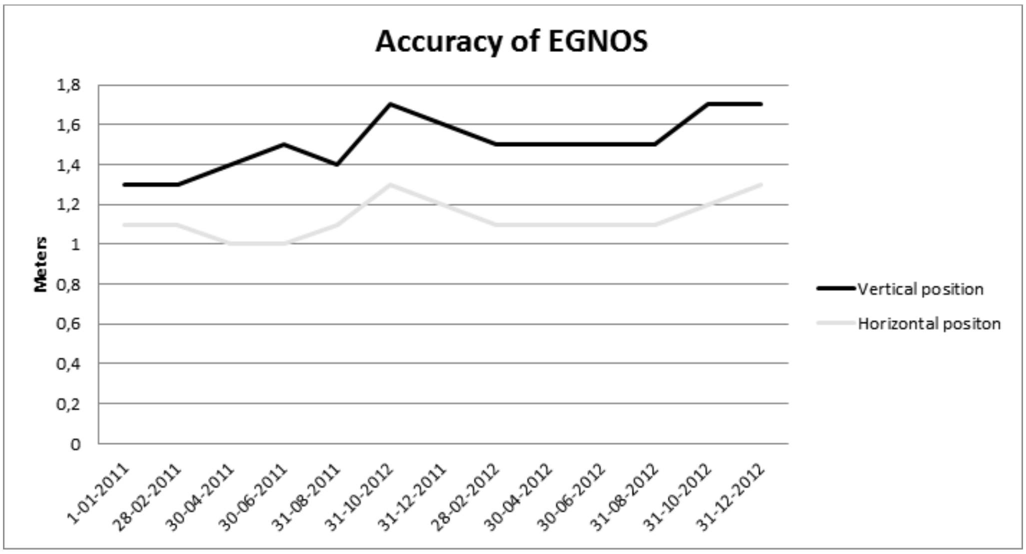


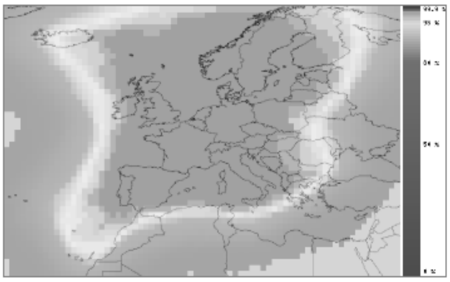
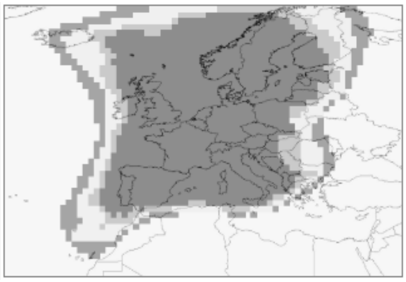
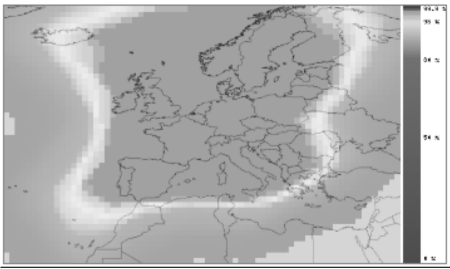
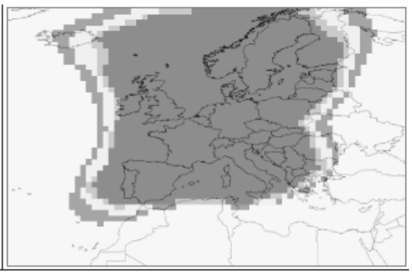
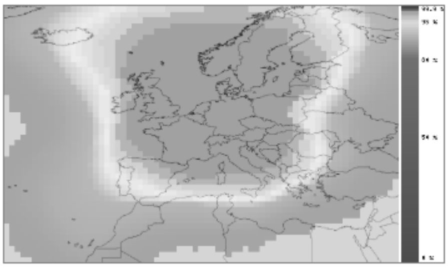
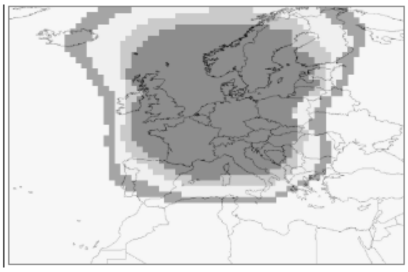
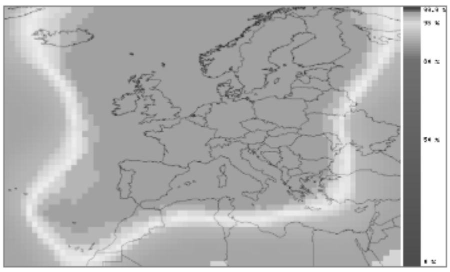
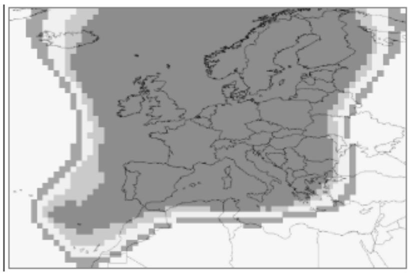
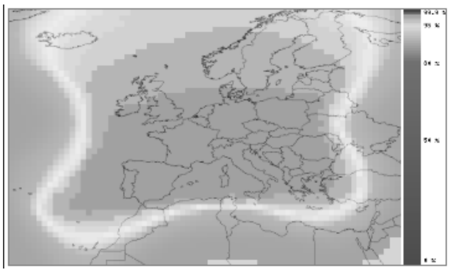
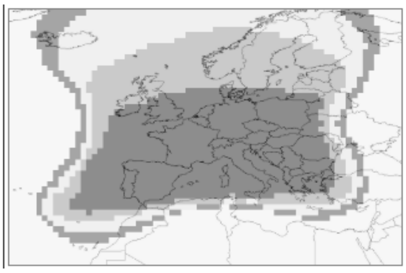
Fig. 2. Accuracy of EGNOS [5]
Rys. 2. Dokładność pomiaru systemu EGNOS [5]

3.2. Availability

Data allows showing very precisely three levels of system availability and display them on the map. Availability less than 95% of operation time is provided for the largest possible areas that have been marked in grey. Availability at the level of 95-98% is a smaller area marked with white. The presence of 100-percent availability is a dark area. Availability is illustrated separately for the values measured horizontally and vertically in the selected time intervals. Availability of EGNOS signal in the previously mentioned levels is presented in Tab. 1.

Table 1

Availability of EGNOS signal in the selected time intervals

Horizontal position	Vertical position
01/01/2011 - 28/02/2011	
	
01/03/2011 - 30/04/2011	
	
01/11/2011 - 31/12/2011	
	
01/07/2012 - 31/08/2012	
	
01/11/2012 - 31/12/2012	
	

3.3. Integrity

The following Fig. 3. presents the integrity performance measured by Safety Index. The Safety Index equals the ratio between the navigation system error and the Protection Level. The higher Safety Index is, the less risk of error.

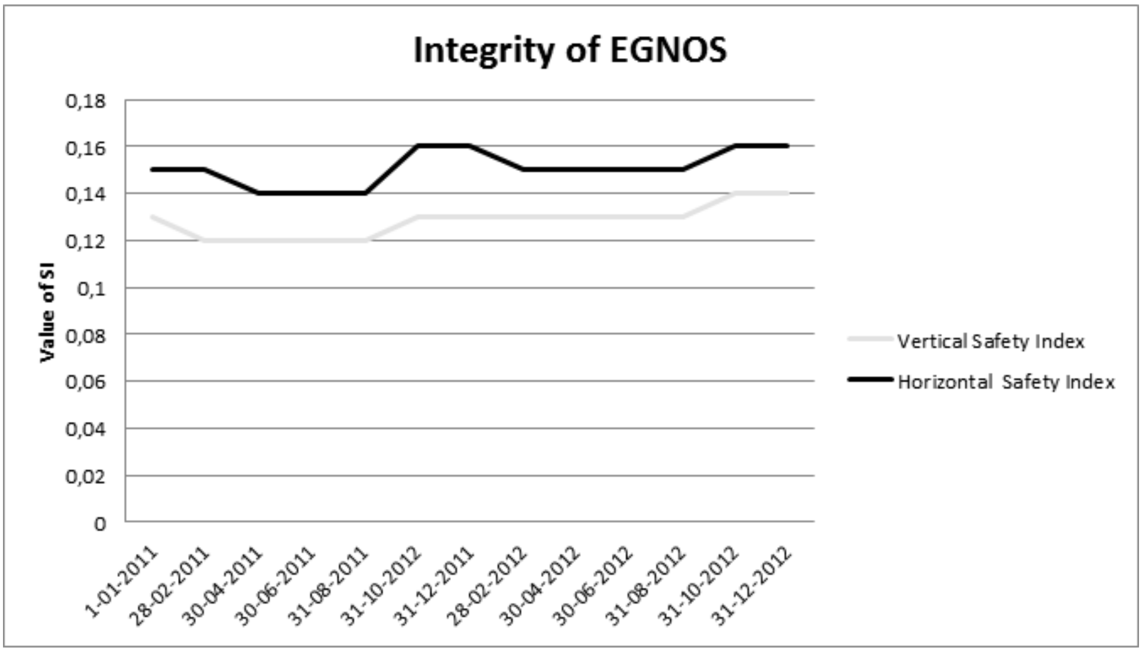


Fig. 3. Integrity of EGNOS [5]
Rys. 3. Wiarygodność pomiaru sygnału systemu EGNOS [5]

3.4. Continuity

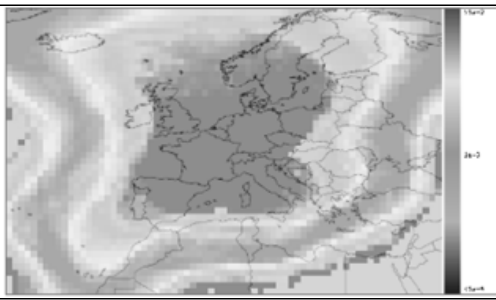
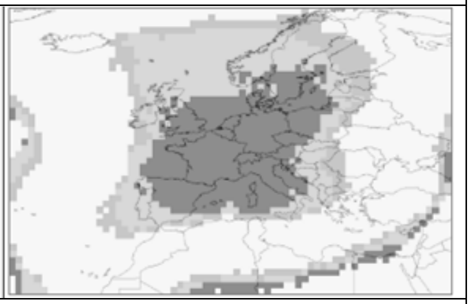
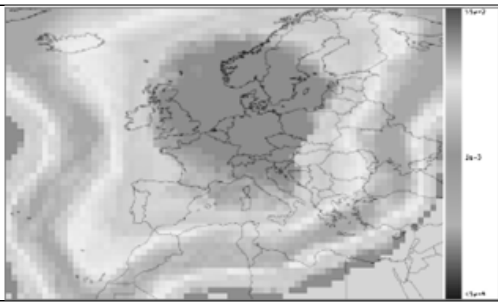
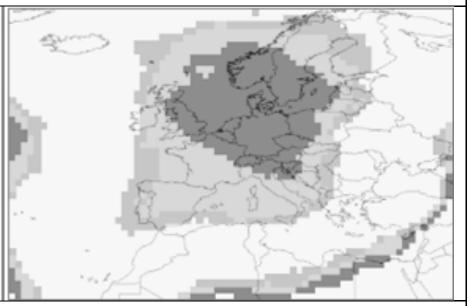
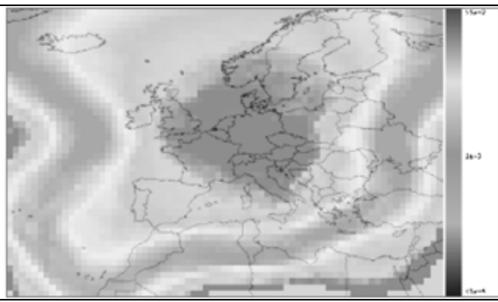
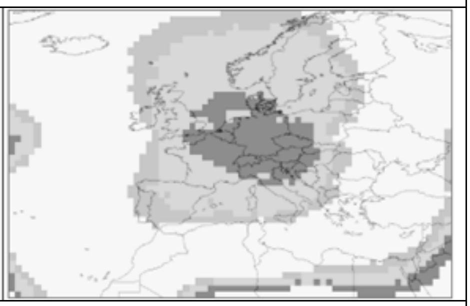
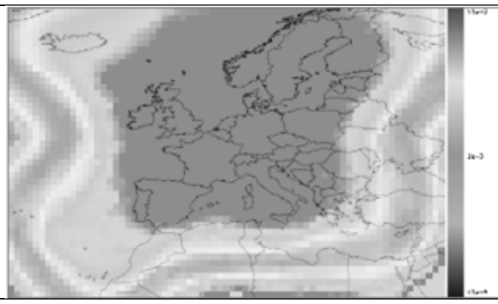
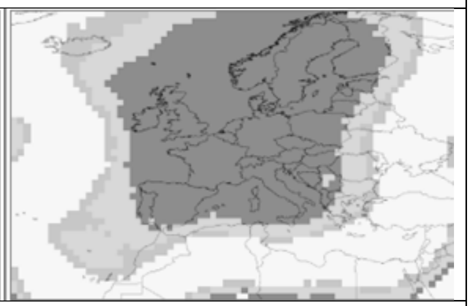
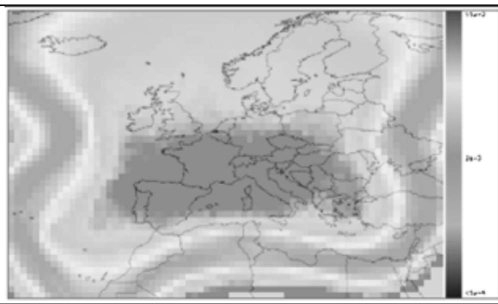
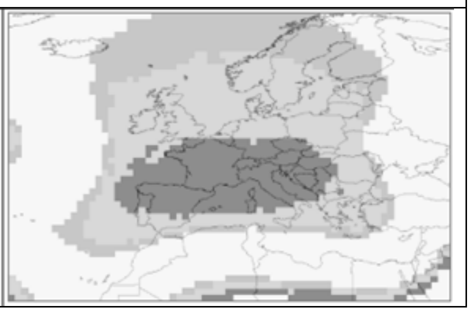
Continuity performances were put into three groups:

- Continuity risk lower than 10^{-4} - marked with dark grey
- Continuity risk between $5 \cdot 10^{-4}$ - 10^{-4} - marked with light grey
- Continuity risk between 10^{-3} - $5 \cdot 10^{-4}$ - marked with white

In 2011, the area of the smallest risk of interruption of the signal decreased gradually in the following months. In 2012, the opposite trend can be observed in the period January - August. In the second half of the year the signal deteriorated. Continuity is illustrated in the Tab. 2 separately for the values measured horizontally and vertically in the selected time intervals.

Table 2

Continuity of EGNOS signal in the selected time intervals

Horizontal position	Vertical position
01/01/2011 - 28/02/2011	
	
01/05/2011 - 30/06/2011	
	
01/01/2012 - 29/02/2012	
	
01/05/2012 - 30/06/2012	
	
01/11/2012 - 31/12/2012	
	

4. EGNOS PERFORMANCES AND REQUIREMENTS OF POLISH TRANSPORT

In order to verify the suitability of the EGNOS, performances were compared with the international requirements for navigation systems in sea, road and rail transport, as well as in aviation [6].

4.1. Road transport

Comparison parameters of EGNOS with road transport criteria shows that the satellite system measured up accuracy requirements, alarm time, coverage area and availability in most of the implementations. As it shown in Tab. 3., in the case of driving with collision avoidance, system does not provide the required accuracy.

Table 3

Requirements for the road transport

Implementation	Accuracy	Availability (%)	Coverage area
Road navigation	5 – 20 m	99,7	State area
Alarm systems	5 – 30 m	99,7	State area
Transportation management	25 – 1500 m	99,7	State area
Driving	30 – 50 m	99,7	State area
Collision avoidance: critical situations	5 m	99,7	Collision area
Accident data collection	30 m	99,7	State area
Infrastructure management	10 m	99,7	State area
Collision avoidance: steering	1m	99,7	Collision area

In 2010 32% of the vehicles on EU roads were equipped with the navigation device. EGNOS receiver in a car or truck can quickly determine its position. As a result, logistics and shipping companies gain valuable tool for fleet management and increase the timeliness of the services. The driver gain reliable system to reporting of theft or an accident, which can reduce the time needed for help. EGNOS can also reduce costs for the company, through better use of their vehicles. The system, after all, allows precisely calculate length of the route and required fuel. Moreover, EGNOS-based road user charging does not need a capital-intensive toll gate infrastructure. For instance, in the Netherlands, the toll system based on satellite technology has reduced CO_2 emissions by 19%.

4.2. Ship transport

EGNOS has shown a full conformance with the requirements of the navigation in harbours and mooring for large and small vessels [10]. Requirements for the ship transport are presented in Tab. 4.

Table 4

Requirements for the ship transport

Implementation	Accuracy	Availability (%)	Coverage area
Shipping in harbours: large vessels	8 – 20 m	99,7	Port
Shipping in harbours: small vessels	8 – 20 m	99,9	Port
Coast shipping: all vessels	460 m (0,25 Mn)	99,7	Coastal waters
Coast shipping: small vessels	460 – 3700 m (0,25 – 2 Mn)	99,0	Coastal waters

EGNOS can be used as support for Vessel Traffic Service (VTS), allowing accurate navigation during bad weather and low visibility or in huge traffic area. It increases the safety of the vessels, passengers and cargo.

4.3. Aviation

EGNOS meets the requirements for aviation, except approaches of III category. Table 5 shows, that system is not able to ensure the vertical accuracy of 0,6 m.

Implementation of EGNOS in airports is mandatory. In line with the government's program of development of airports and aviation ground equipment, implementation of Approach using Vertical Guidance (APV) supported by EGNOS should end in 2020 [7]. It helps to reduce the costs of airports. EGNOS eliminate a need to build expensive Instrument Landing System (ILS). For the owners of airports it means savings up to 6 million PLN [8].

EGNOS gives an average of 1-4 meters accuracy for horizontal position and 1,5-4 meters in height. Deviations very rarely exceed the value of 10 meters. EGNOS and precise approach minimize the risk of accidents in the hard-landing places, like oil platforms and airports in mountains. The system enhances the safety of flight, especially during take-off and landing phases. As Civil Aviation Authority reported, nearly 62% of aviation accidents in Polish and with Polish aircrafts took place during the landing or take-off phase [9].

Table 5

Requirements for the aviation

Type of operation	Accuracy	Availability (%)
Transoceanic flights	23 km (12,6 Mn)	99,977
Domestic flights	1000 m	99,977
Terminals	500 m	99,977
Non-precision approach	100 m	99,977
Precision approach cat. I	Vertical: 17,1 m Horizontal: 1,7 m	99,999
Precision approach cat. II	Vertical: 5,2 m Horizontal: 1,7 m	99,999
Precision approach cat. III	Vertical: 4,1 m Horizontal: 0,6 m	99,999

4.4. Rail transport

EGNOS can be used to track the position of the trains and to measure their speed. Fluctuation of parameters in the analyzed period does not allow for driving trains and alarming. The 1 meter accuracy was provided during one period May - June 2011. Results of selected RGNOS parameters for the rail transport are presented in Tab. 6.

Table 6

Requirements for the rail transport

Implementation	Accuracy	Availability (%)	Coverage area
Tracking	10 – 30 m	99,7	State area
Driving	1 m	100	State area
Alarming	1 m	100	State area

5. CONCLUSIONS

Analysis of the performances of EGNOS shows that, in the case of Poland, the systems fulfil most of the requirements for navigation systems in sea, road, rail transport and aviation. Moreover, at the end of analyzed period EGNOS was available in the whole country. This means that EGNOS, as other GNSS recommended by ICAO [14], can and should be used by state agencies and private companies as support for traffic management systems. However, it is necessary to continue development and improvement of EGNOS.

References

1. *Galileo will boost economy and make life of citizens easier*. Available at: http://europa.eu/rapid/press-release_MEMO-11-717_en.htm?locale=en.
2. *Europa na szlaku nawigacji satelitarnej.* [In Polish: *Europe on track with satellite navigation*]. Available at: http://ec.europa.eu/news/business/110119_pl.htm.
3. *The need for EGNOS*. Available at: http://egnos-user-support.essp-sas.eu/egnos_ops/node/295.web.
4. *EGNOS Service Definition Document – Open Service.* Brussels Directorate-General for Enterprise and Industry of European Commission. 2013. P. 10-13. Available at: http://ec.europa.eu/enterprise/newsroom/cf/_getdocument.cfm?doc_id=7843.
5. *EGNOS Data Collection Network (EDCN)*. Available at: http://edcn2.pildo.com/home/.
6. Fellner, A. *Analiza systemów nawigacyjnych i koncepcja stacji permanentnych RTK DGPS dla potrzeb lotnictwa.* [In Polish: *Analysis of navigation systems and the framing of permanent stations RTK DGPS for aviation requirements*]. Dęblin: Wydawnictwo WSOSP. 1999.
7. *Program rozwoju sieci lotnisk i lotniczych urządzeń naziemnych.* Uchwała Rady Ministrów Nr. 86. 2007. [In Polish: *Development programme for network of airports and ground equipment.* Resolution of the Council of Ministers].
8. *EGNOS - prawdy i mity*. [In Polish: *EGNOS - truths and myths*]. Available at: http://dlapilota.pl/wiadomosci/dlapilota/egnos-prawdy-i-mity-czesc-druga.
9. *Polish aviation accidents and incidents in 2011*. Available at: http://www.ulc.gov.pl.
10. *Compare with minimum maritime user requirements for positioning: Revised maritime policy for a future GNSS*. Resolution A.915 (22). International Maritime Organization. 2002. P. 16-20.
11. Januszewski, J. *Systemy satelitarne GPS, Galileo i inne.* [In Polish: GPS, Galileo and other satellite systems]. Warszawa: PWN. 2010.
12. Spilker, J. *GPS signal structure and theoretical performance.* In: Parkinson, B. & Spilker, J. *Global Positioning System.* Vol. 1 and 2. Washington D.C. 1996.
13. Mechet, Ch. & Poirier, J. & Husson, J. *System nawigacyjny Galileo – aspekty strategiczne, naukowe i techniczne.* [In Polish: *A positioning system Galileo: strategic, scientific and technical stakes*]. Warszawa: WKiŁ. 2006.
14. *The 2015 airspace concept & strategy for the ECAC area.* Eurocontrol. Brussels, 28 February 2008.
15. Belinska, V. & Kluga, A. & Kluga, J. & Bricis A. Accuracy estimation of TOPCON GRS-1 GNSS receiver parameters in static and dynamic mode. *Elektronika ir elektrotechnika.* 2014. Vol. 20. No. 2. P. 89-92.
16. *Annex 10. Aeronautical telecommunications.* Vol. 1. 6th edition. ICAO. Montreal. 2006. P. 316-321.
17. *Draft version of new EUR Air Navigation Plan.* Vol. I. Basic ANP. ICAO European and North Atlantic Regions. 2012.

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