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THE AVAILABILITY OF AUTOMATIC IDENTIFICATION SYSTEM (AIS) BASED ON LATENCY POSITION REPORTS IN THE GULF OF GDANSK

ABSTRACT

The problem of determining geographic position considered only in terms of measurement error, seems to be solved on a global scale. In view of the above, from the nineties, the operational characteristics of radio-navigation systems are equally important. The integrated navigation system operate in a multi-sensor environment and it is important to determinate a temporal validity of data to make it usable in data fusion process. In the age of digital data processing, the requirements for continuity, availability, reliability and integrity information are already grown. This article analyses the problem of time stamp discrepancies of dynamic position reports. For this purpose, the statistical summary of Latency Position Reports has been presented. The navigation data recordings were conducted during 30 days of March 2014 from 19 vessels located in area of Gulf of Gdansk. On the base of Latency Position Reports it is possible to designate the availability of AIS system.

Keywords:
Automatic Identification System (AIS), stochastic processes, availability of AIS service.

BACKGROUND

Radio-navigation devices such as Radar or ARPA contain several limitations concerned with transferring continuous and reliable data. These limitations result from the absence of the possibility to detect radar echo under adverse weather conditions during a maneuver executed by a vessel. It is important that the radar data be supplemented with data coming from a system working on continuous basis, with data whose accuracy is comparable to the data coming from GNSS. AIS seems to be such a system. This paper presents analysis of data availability related to time stamps discrepancies using stochastic processes. Data recorded in the Institute of Marine Navigation and Hydrography in March 2014 have been used to conduct analyses.

Automatic Identification System (AIS) is a data exchange system which has been introduced to improve shipping safety and the possibility of exchanging data related to ships heading to or from ports, as well as exchanging data relating to passengers and dangerous or environment-polluting cargo carried by ships. The main aim of introducing AIS was to offer an available, continuous and reliable navigational data. Apart from usefulness for traffic control AIS messages can be a very important source of data to be used for making decisions related to collision avoidance. However, some reservations are voiced with regard to the unconditional reliance on the data transferred through this channel. Thus, it is justifiable to ask the question to what extent data coming from AIS is available and reliable [Jaskólski K., 2013].

On the basis of the studies on the technical specification of the ITU R.M.1371 system, one can draw the assumption that errors classified as lack of reliability will depend on the performance of sensors co-working with AIS and human errors made by operators, and those fitting the devices [Jaskólski K., 2013].

At present GPS is available all-round the Earth and permanently, so the problem of fixing position co-ordinates for marine navigation purposes considered in categories of satisfactory accuracy of measurement seems to have been solved. Its realization is only a function of the technical solution employed. Nowadays any GNSS variations are commonly used, and EGNOS, commonly available in Europe (as well as WAAS in North America), offers accuracy satisfying almost all users [Felski et al., 2011]. In this situation, equally important, but often neglected operation characteristics of radio-navigation systems, such as availability, continuity, reliability and integrity are of increasing importance. However, treating AIS as radio-navigation system is disputable. It is actually a radio channel for data transmission. That is why the notion of data availability is used in the paper. This measure will be expressed with statistical methods [Jaskólski K., 2013].

The article presents the latency of data transmission problem. It is proposed to identify the latency of received data with AIS data transmissions availability. Similar investigations have been conducted by [Banyś P. et al., 2013].

THE NOTION OF AIS AVAILABILITY

System fault can be determined as a state, which makes the system working improperly. It means that the system fault may be considered a state caused by failure of any internal or external element like failure of radio link (excessive noise level).

These causes lead to appearance of specified time period called Time to Repair (TTR). According to [IALA, 1989] mean value of TTR may be used for estimation of availability. Availability can be calculated as the ratio of total time during which the system was available to the total period of time under consideration.

$$A = \frac{MTBF}{MTBF+MTTR}, \quad (1)$$

where:
MTBF — Mean Time Between Failures;
MTTR — Mean Time To Repair.

If we consider the navigational structure of system operating in time, then X_1, X_2, X_3, … X_n will be the working time and Y_1, Y_2, Y_3, … Y_n will be the time of failure. The moments $Z'_n = X_1+Y_1+X_2+Y_2+\ldots+Y_{n-1}+X_n$, n = 1, 2, …, N are moments of failures and $Z''_n = Z'_n+Y_n$ are moments of renewal [Specht C., 2003]. In addition, X_1, $Y_{1,}$ i = 1, 2,… are independent and the working times and times of failures have the same distributions. The working state is binary 1, the state of failure is binary 0. Graphic presentation of Availability of AIS Position Reports is presented in figure 1.

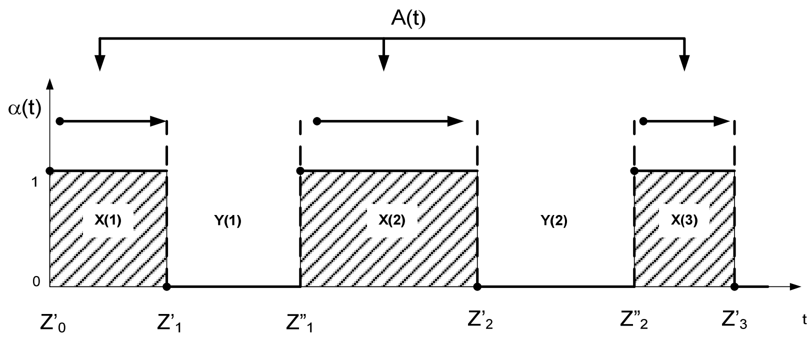

Fig. 1. Graphic presentation of Availability of AIS Position Reports:
A(t) — availability of AIS Position Reports;α(t) — system state; X(n) — working time; Y(n) — time of failure [source: Specht C., 2003]

If:

$$MTBF = \frac{X_1+X_2+X_3+\ldots+X_n}{n}; \quad (2)$$

$$MTTR = \frac{Y_1+Y_2+Y_3+\ldots+Y_n}{n}, \quad (3)$$

we obtain:

$$A = \frac{\frac{X_1+X_2+X_3+\ldots+X_n}{n}}{\frac{X_1+X_2+X_3+\ldots+X_n}{n}+\frac{Y_1+Y_2+Y_3+\ldots+Y_n}{n}}. \quad (4)$$

Then:

$$\frac{X_1+X_2+X_3+\ldots+X_n}{n} \to E(X); \quad (5)$$

$$\frac{Y_1+Y_2+Y_3+\ldots+Y_n}{n} \to E(Y), \quad (6)$$

where:

$E(X)$ — expected value of working time;

$E(Y)$ — expected value of time of failure.

Finally:

$$A = \frac{E(X)}{E(X)+E(Y)}. \quad (7)$$

Availability of the AIS binary data can be referred to any time interval in which it is estimated. The most competent representation of the availability is its limiting value, which is defined as an availability coefficient — A.
Therefore:

$$A = \lim_{t\to\infty} A(t) = \lim_{t\to\infty} \frac{1}{E(X)+E(Y)} \int_0^\infty R(u)du, \quad (8)$$

where:

$$\int_0^\infty R(u)du = E(X); \quad (9)$$

$\int_0^\infty R(u)du$ — reliability function.

Operating navigation system — AIS can be characterized by an exponential distribution of residence times of working and failure states due to the ‘memoryless’. AIS binary data availability has an exponential distribution if the density function of the random variable T — Time to Failure (TTF) is given by [Specht C., 2003]:

$$f(t) = \begin{cases} \lambda e^{-\lambda t} & t > 0 \\ 0 & t \le 0 \end{cases}. \quad (10)$$

Then, cumulative distribution function of the random variable T (TTF) is given by:

$$F(t)=\begin{cases}1-e^{-\lambda t} & t>0\\ 0 & t\leq 0\end{cases}; \tag{11}$$

$$G(t)=\begin{cases}1-e^{-\mu t} & t>0\\ 0 & t\leq 0\end{cases}. \tag{12}$$

Where λ is failure rate and μ denotes reneval rate.

From the properties of the exponential distribution [Specht C., 2003]:

$$E_{\exp}(X_i)=\frac{1}{\lambda,}; \tag{13}$$

$$E_{\exp}(Y_i)=\frac{1}{\mu}, \tag{14}$$

where:

$E_{\exp}(X_i)$ — expected value of the exponential life distribution;

$E_{\exp}(Y_i)$ — expected value of the exponential failure distribution.

Finally, we obtain [Specht C., 2003]:

$$A_{\exp}(t)=\frac{\mu}{\lambda+\mu}+\frac{\lambda}{\lambda+\mu}e^{-(\lambda+\mu)t}, \tag{15}$$

where:

$A_{\exp}(t)$ — exponential distribution of availability system.

AVAILABILITY STRUCTURE OF AIS SYSTEM — DETERMINATION OF THE OBJECT STUDY

The reliability structure of AIS might be defined by interval time between two consecutive AIS position reports received from the same vessel, which decides about its state. Let $\alpha(t)$ be the binary interpretation of the availability state of the process [Specht C., 2003].

$$\alpha(t) = \begin{cases} 1, \; Z"_n \leq t < Z'_{n+1} \\ 0, \; Z'_{n+1} \leq Z"_{n+1} \end{cases} \quad for\; n = 0,1,2,\ldots N. \tag{16}$$

The state $\alpha(t) = 1$ means that in the moment t the interval time between two consecutive position reports received from the same vessel is less than 30 s if the speed is less than 14 knots or 18 s if the speed is at the range from 14 to 23 knots or 6 s if the speed exceed 23 knots and in the moment t the position error δ_n is less than U = 10 m. The system is in the working state.

In the opposite case $\alpha(t) = 0$, the interval time between two consecutive AIS position reports received from the same vessel exceed 30 s if the speed is less than 14 knots or exceed 18 s if the speed is at the range from 14 to 23 knots or exceed 6 s if the speed exceed 23 knots in the moment t or for position error $\delta_n > 10$ m. The system is in the state of failure.

It was adopted that, 30 seconds is enough time to refresh the dynamic data during anti-collision manoeuvring if the speed is less than 14 knots or 18 s if the speed is at the range from 14 to 23 knots or 6 s if the speed exceed 23 knots and in the moment t. AIS binary transmission unfitness is the result of not receiving the next three Position Reports. Reporting Intervals between two consecutive AIS position reports received from the same vessel equipped with AIS Class A receiver was presented in table 1. Reporting intervals are in the range from 2 to 10 s if the vessel is 'on the way'.

Table 1. Class A shipborne mobile equipment reporting intervals [ITU, 2010]

Ship's dynamic conditions	Nominal reporting interval
Ship at anchor or moored and not moving faster than 3 knots	3 min
Ship at anchor or moored and moving faster than 3 knots	10 s
Ship 0–14 knots	10 s
Ship 0–14 knots and changing course	3,33 s
Ship 14–23 knots	6 s
Ship 14–23 knots and changing course	2 s
Ship > 23 knots	2 s
Ship > 23 knots and changing course	2 s

The accuracy level of vessel position is determined on the basic of GPS Quality Indicator and of Age of Differential GPS Data and Time in seconds since last SC104 was updated. GGA sentence contains information about GPS and Differential GPS Data Quality.

RECORDING SIGNALS, OPERATING DATABASE

The post-processing method was used in order to conduct statistical analyses of AIS messages recorded. The station for recording AIS signals was prepared in the

Institute of Navigation and Marine Hydrography, at the Gdynia Naval Academy. The data was recorded on the data carrier of a signal recorder with sentence VDM. Position Reports (message No. 1) was used to analyze the data. The data recorded date was for the March 2014. They were recorded in text files. Figure 2 shows the onshore setup of the AIS traffic data acquisition.

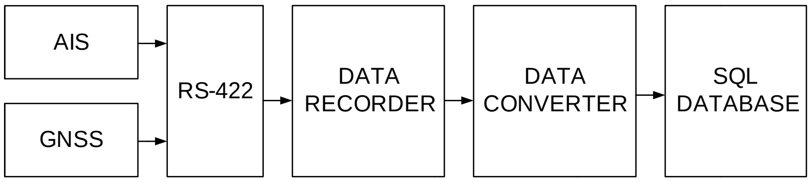

Fig. 2. The onshore station setup of the AIS traffic data acquisition

With the above configuration it is possible to conduct a measurement campaign and have a synchronised collection of data streams, which will serve as groundwork for analysis of signals latency in multi-sensor NMEA environment.

A VDM sentence contains navigational datasets of vessels, which are received from other vessels equipped with AIS transponder in area of VHF operation zone. This data are encapsulated according to [ITU, 2010] specification. Afterwards, the comparison of AIS timestamps and GNSS time has been carried out. Database connectivity GNSS and AIS was conducted by IBExpert Database Client type.

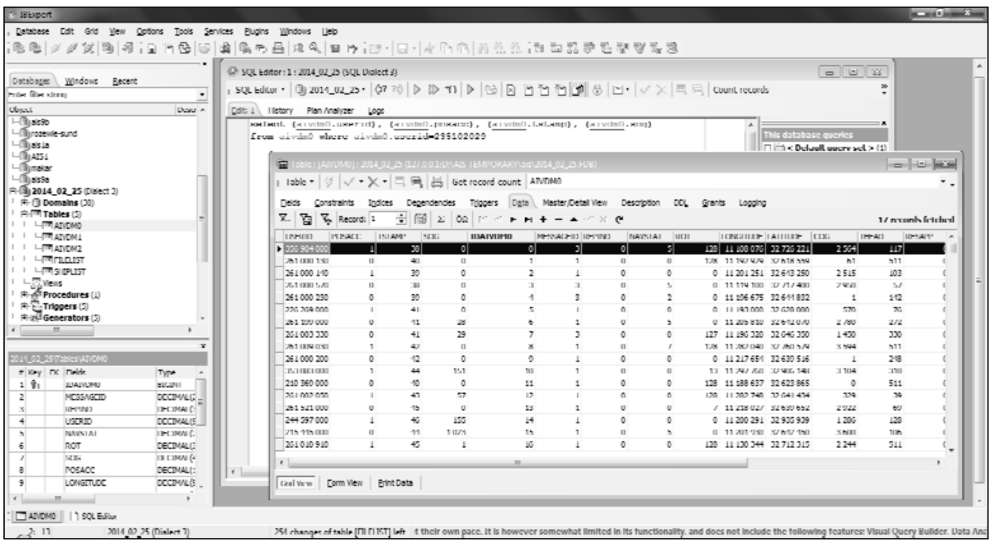

Fig. 3. IB Expert database with records indexing by MMSI and timestamps

ANALYSIS OF AIS AVAILABILITY

The examination of AIS data availability was conducted from 25 February to 30 March of 2014. Registrations were carried out using a stationary device AIS SAAB R4 as a tool of Institute of Navigation and Hydrography Laboratory. Post-processing methodology was used to carry out research. Nineteen vessels were selected for carry out availability research of AIS data. Information on delays of the received signals and accuracy position of SBAS are used within the proposed research model. Recorded database consists of 201 498 records from 19 selected vessels.

Investigation outcomes are presented in table 2. According to model assumption, transitions between states of the process, number of failure states, number of working states, time of failure and working time were segregated according to the number of measurement session. Differences in amounts of registered records are the result of the residence time of vessels in the Gulf of Gdansk, speed manoeuvring, heading changes and navigation status.

Light grey and dark grey fields in the table 2 show the minimum and maximum parameter values.

Taking into account the research results of 19 sessions, the system was in working state in 177 013 cases. Constancy of this state was recorded in 170 949 cases and its total duration of selected sessions amounted to 12 days 19 hours 49 minutes and 9 seconds. The system was in state of failure in 7 678 cases, because interval time between two consecutive AIS position reports received from the same vessel exceed 30 s if the speed is less than 14 knots or exceed 18 s if the speed is at the range from 14 to 23 knots or exceed 6 s if the speed exceed 23 knots in the moment t or for position error $\delta n > 10$ m.

Table 2. Research outcomes

Number of sessions	Number of records	Transitions between states of the process				Number of failure states	Number of working states	Y(n) time of failure (s)	X(n) working time (s)
		0→0	0→1	1→0	1→1				
1	11496	431	452	453	10159	883	10612	5298	63672
2	3859	186	161	161	3350	347	3511	2082	21066
3	18988	179	585	585	17639	764	18224	4584	109344
4	3212	20	89	90	3013	109	3103	654	18618
5	4043	32	397	397	3217	429	3614	2574	21684
6	31046	206	1660	1660	27520	1866	29180	11196	175080
7	30251	135	569	569	28979	704	29548	4224	177288
8	12712	119	505	505	11583	624	12088	3744	72528

9	5465	56	232	233	4944	288	5177	1728	31062
10	1320	3	26	26	1265	29	1291	174	7746
11	2111	15	146	147	1803	161	1950	966	11700
12	2737	9	71	70	2587	80	2657	480	15942
13	1684	6	67	67	1543	73	1610	438	9660
14	4462	5	28	28	4400	33	4428	198	26568
15	1092	9	39	39	1005	48	1044	288	6264
16	2671	29	242	243	2158	271	2401	1626	14406
17	47833	24	302	302	30417	326	30719	1956	184314
18	1628	12	43	44	1529	55	1573	330	9438
19	14870	144	444	445	13838	588	14283	3528	85698

The outcomes for expected value of system lifetime $E(X)$ and expected value of system failure time $E(Y)$ for 19 sessions are presented below:

$$E_{exp}\ X_i \ = 55898\, s;$$

$$E_{exp}\ Y_i \ = 2424\, s.$$

In accordance with reliability theorem, on the basis of $E(X)$ and $E(Y)$ outcomes, it is possible to designate λ failure rate and μ is denoted as renewal rate.

The outcomes for failure rate λ and renewal rate μ for 19 sessions are presented below:

$$\lambda = 0{,}000018 \frac{1}{s};$$

$$\mu = 0{,}000412 \frac{1}{s}.$$

Finally we obtain [Specht C., 2003]:

$$A_{exp}\ t \ = 0{,}958437.$$

The connected GNSS receiver indicates the availability of RAIM process by valid GBS sentence of IEC 61162-1; in this case RAIM-flag should be set to ‘1’. The threshold for evaluation of RAIM information is 10 m. RAIM expected error is calculated on the basis of the GBS parameters ‘expected error in latitude’ and ‘expected error in longitude’ using the following formula:

$$\textit{Expected RAIM Error} = \sqrt{(\textit{expected error in latitude})^2 + (\textit{expected error in longitude})^2}\ . \quad (17)$$

Determination of position accuracy was presented in table 3.

Table 1. Determination of position accuracy information [ITU, 2013]

Accuracy status from RAIM (for 95% of position fixes)	RAIM flag	Differential correction status	Resulting value of PA flag
No RAIM process available	0	Uncorrected	0 = low (> 10 m)
EXPECTED RAIM error is < 10 m	1		1 = high (< 10 m)
EXPECTED RAIM error is > 10 m	1		0 = low (> 10 m)
No RAIM process available	0	Corrected	1 = high (< 10 m)
EXPECTED RAIM error is < 10 m	1		1 = high (< 10 m)
EXPECTED RAIM error is > 10 m	1		0 = low (> 10 m)

Graphical presentation of availability according to latency of received messages, GNSS position accuracy and geographical positions of ships with the determination of the level of position accuracy for 3, 16, and 18 session were illustrated in figures 4–12.

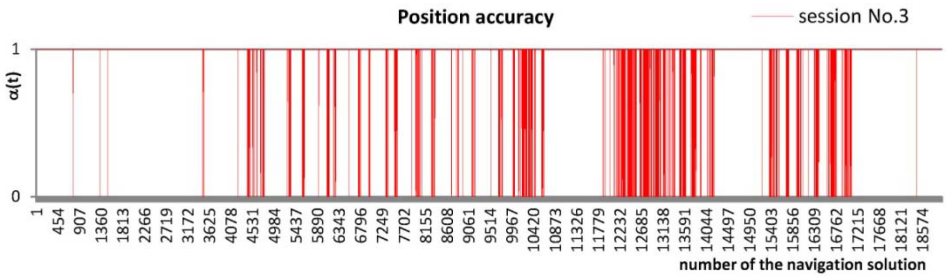

Fig. 4. Working state [value: 1] and state of failure [value: 0] of the availability of the SBAS position (2014.02.28) for U = 10 m, based on AIS dynamic data from session No. 3

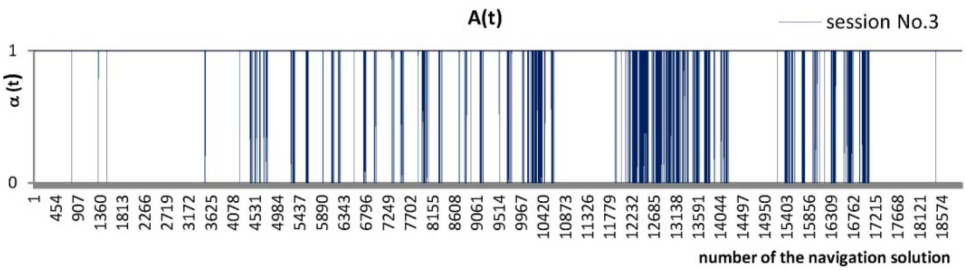

Fig. 5. Working state [value: 1] and state of failure [value: 0] of the availability of the AIS (2014.02.28) according to model assumptions, based on AIS dynamic data from session No. 3

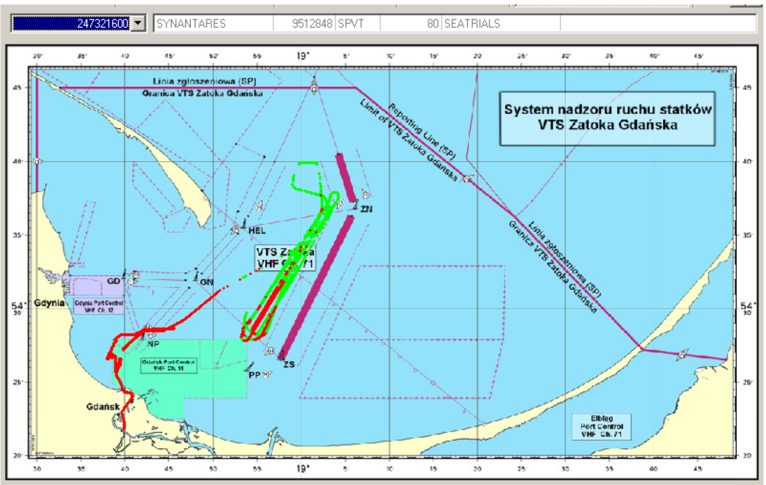

Fig. 6. Geographic positions of session No. 3 during the voyage in area of VTS Gulf of Gdansk; green dots — working state: position error $\delta_n \leq 10$ m, Red dots — state of failure: $\delta_n > 10$ m

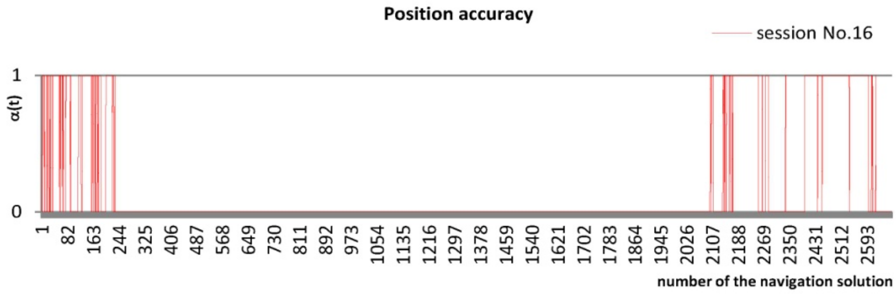

Fig. 7. Working state [value: 1] and state of failure [value: 0] of the availability of the SBAS system position (2014.03.04) for U = 10 m, based on AIS dynamic data from session No. 16

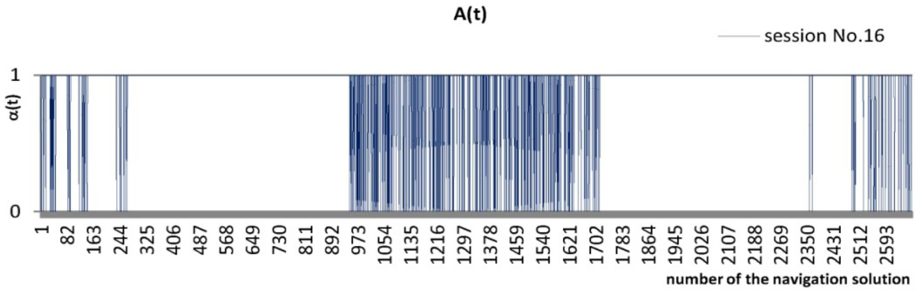

Fig. 8. Working state [value: 1] and state of failure [value: 0] of the availability of the AIS (2014.03.04) according to model assumptions, based on AIS dynamic data from session No. 16

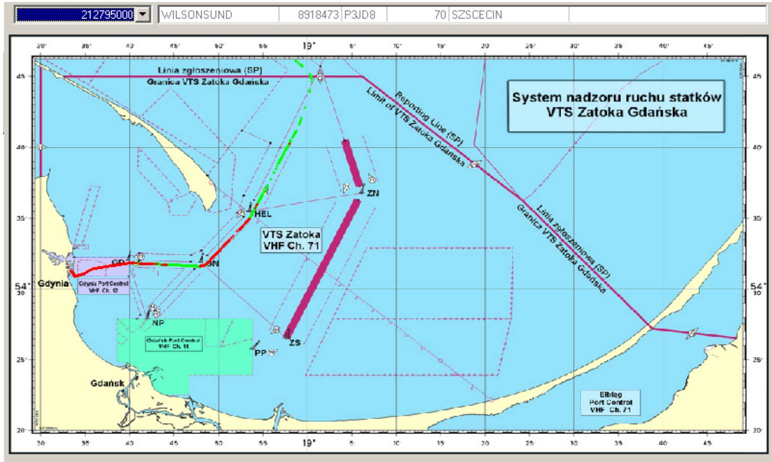

Fig. 9. Geographic positions of session No. 16 during the voyage in area of VTS Gulf of Gdansk; green dots — working state: position error $\delta_n \leq 10$ m, red dots — state of failure: $\delta_n > 10$ m

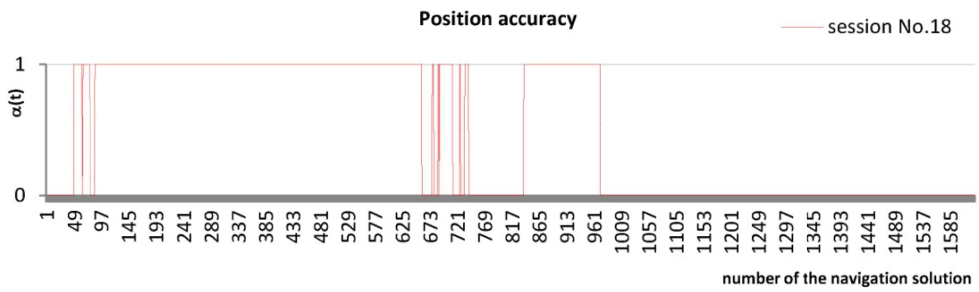

Fig. 10. Working state [value: 1] and state of failure [value: 0] of the availability of the SBAS system position (2014.03.14) for U = 10 m, based on AIS dynamic data from session No. 18

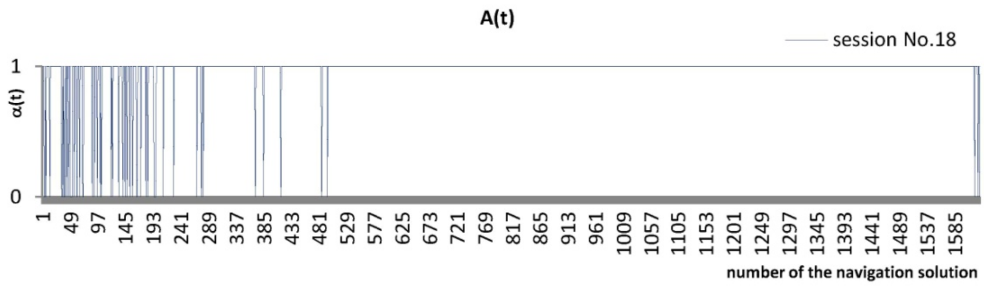

Fig. 11. Working state [value: 1] and state of failure [value: 0] of the availability of the AIS (2014.03.14) according to model assumptions, based on AIS dynamic data from session No. 18

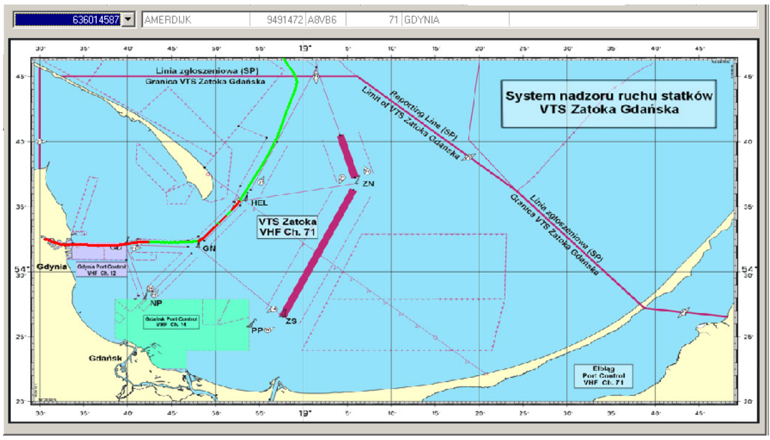

Fig. 12. Geographic positions of session No. 18 during the voyage in area of VTS Gulf of Gdansk; green dots — working state: position error $\delta_n \leq 10$ m, red dots — state of failure: $\delta_n > 10$ m

Detailed breakdown of data presented in the figures (availability, accuracy) are located in table 2. Absolute accuracy for U = 10 m adopted as the limit value which can be used in the coastal and port approach navigation is resulted from IMO Resolution A.915(22), A.1046(27). Geographic positions of session No. 3, 16, 18 during the voyage in area of VTS Gulf of Gdansk were presented in figures 6, 9, 12. Green dots illustrated working state — position error $\delta_n \leq 10$ m, red dots illustrated state of failure — $\delta_e > 10$ m.

ANALYSIS OF AIS TIME STAMPS

The number of position reports according to time stamps and the percentage of position reports according to time stamps were presented in figures 13 and 14.

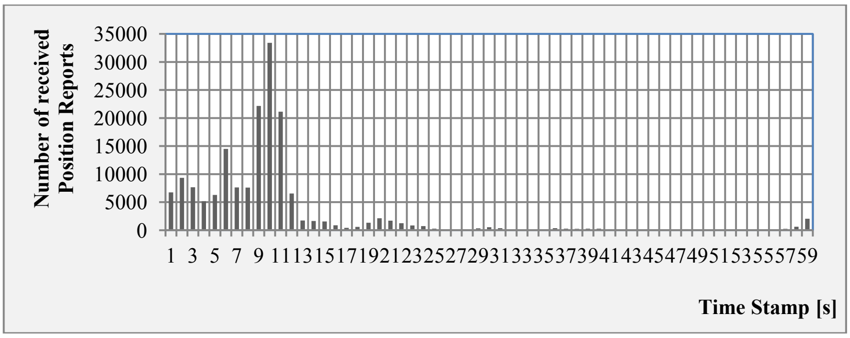

Fig. 13. The number of position reports according to time stamps; time interval 1 s

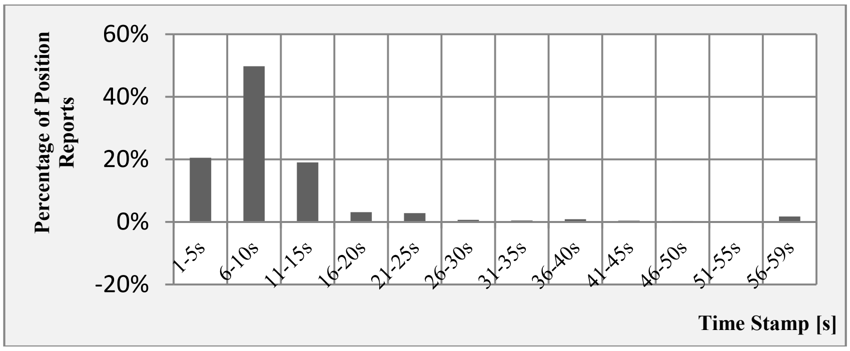

Fig. 14. The percentage of position reports according to time stamps; time interval 5 s

It has been observed that 49.75% of position reports were received in 6–10 s time intervals. This value corresponds to the number of 85 305 AIS position reports. Approximately 20.52% of position reports were received in 1–5 s time intervals. This value corresponds to the number of 35 188 AIS position reports. Presented outcomes are associated with the technical specifications of the system and time interval of position reports illustrated in table 1. All these Position Reports have originated from vessels 'on the way'. Other outcomes resulted from potential delays of received information.

CONCLUSION

In the face of rapid growth of the availability and accuracy of satellite systems in the latter part of XX century the problem of positioning is not so critical as in the previous time. Accordingly, characteristics of radio-navigation systems, such as reliability of position, are equally important. The proposed solution involves the use of AIS Position Report to estimate availability of AIS binary data. The availability model of AIS binary data according to latency position reports and accuracy position was based on AIS Position Reports. For this purpose, expected value of working time, expected value of time of failure, failure rate and renewal rate and the AIS availability coefficient were designated. Additionally, the availability states of the process were defined. The post-processing method was used in order to conduct statistical analyses of AIS messages recorded. The data recorded date was for the March 2014. Only 19 sessions form vessels in area of 'VTS Zatoka Gdanska' have been used to determinate AIS availability. The statistical analysis of time stamps of recorded Position Reports has been carried out. It has been observed that approximately

50% of position reports were received in 6–10 s time intervals and adequately about 40% of reports were received in 1–5 s and 11–15 s time intervals.

In case of the use of information coming from various sources, it is important to determinate navigational characteristic of data, in order to make it usable in data fusion process. Presented examples prove how important is to apply the integrity data products in real time. The investigation was performed for the application of AIS information in the process of data fusion.

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STRESZCZENIE

Problem określania pozycji geograficznej, z racji powszechnej dostępności systemów satelitarnych, w kontekście dokładności wyznaczeń wydaje się obecnie drugorzędny w skali globalnej. Od lat dziewięćdziesiątych ocena własności operacyjnych systemów radionawigacyjnych jest uważana za równie ważną. Zintegrowane systemy nawigacyjne działają w środowisku wielosensorowym i bardzo ważne staje się określenie zmienności w czasie danych nawigacyjnych, jeśli mają one podlegać fuzji. W erze cyfrowego przetwarzania danych wymagania ciągłości, dostępności, niezawodności i wiarygodności informacji wzrastają. W artykule zaprezentowano analizę problemu niezgodności znacznika czasu w odniesieniu do informacji dynamicznej w kontekście informacji o pozycji. W tym celu poddano analizie statystycznej opóźnienie informacji o pozycji. Rejestracje danych z dziewiętnastu statków były prowadzone przez trzydzieści dni marca 2014 roku na akwenie Zatoki Gdańskiej. Wykazano, że na bazie informacji o opóźnieniu raportów pozycyjnych możliwe jest wyznaczenie dostępności systemu AIS.