DOI: 10.1515/aon-2015-0020

KRZYSZTOF JASKÓLSKI
Polish Naval Academy, Gdynia, Poland

MARITIME SAFETY IN TERMS OF THE AVAILABILITY FOR THE AIS CLASS B BINARY DATA TRANSMISSION, BASED ON STATIC MEASUREMENTS, PERFORMED ON THE VTS ZATOKA GDAŃSKA

ABSTRACT

The problem of the safety navigation considered only in terms of position error measurement, seems to be solved on a global scale. Thus, the operational characteristics of radio navigation systems such as availability 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 AIS class B position reports. For this purpose, the statistical summary of Latency Position Reports, derived from class B units has been presented. The navigation data recordings were conducted during 82 days of August, September and November 2014 from 20 vessels located in area of VTS 'Zatoka Gdańska'. On the base of Latency Position Reports class B it is possible to designate the availability of AIS information system. For this purpose, the model of availability of AIS binary data transmission and research outcomes have been presented.

Keywords:
maritime safety, AIS, AIS availability, VTS.

INTRODUCTION

In the 21st Century, maritime navigation focuses on the application of recent solutions based on information technologies and spatial information systems. The trend is determined among others by International Maritime Organization (IMO) that implemented the concept of e-navigation according to IMO STW 42/6 [IMO, 2010] i.e. navigation supported by advances in telematics. Information technologies, the vessels are equipped in, use computer applications to monitor the processes taking place during cargo handling operations, maneuvering, performing tasks as a vessel on the way. Quick access to information has become a guarantee of safe navigation. Technologies of information systems, geographic information systems (GIS), electronic chart display and information system (ECDIS) and automatic identification system (AIS) offer new opportunities of performing navigational tasks. Information systems are also installed on non-SOLAS vessels in order to improve the safety of navigation. Such devices include AIS Class B installed eg. on sea yachts. The details of AIS Class B operation are shown later in this paper. The purpose of the presented research outcomes is to point out limitations of AIS Class B availability.

GENERAL INFORMATION CONCERNING AIS WITH EMPHASIS ON CLASS B AIS FOR NON-SOLAS VESSELS

AIS is an information system that was implemented for navigational safety improvement and to provide the possibilities of exchanging data on the vessels on the way, both on domestic and international level. It also carries the information on passengers, dangerous or environment-polluting cargo. Currently, AIS are assembled on SOLAS vessels (Class A), Aids To Navigation (AtoN AIS), base stations, as an element of coastal infrastructure system and on non-SOLAS vessels (Class B). The concept of AIS operation AIS Class B uses Self-Organized Time Division Multiple Access (SOTDMA). It also uses Carrier Sense Time Division Multiple Access (CSTDMA) that monitors the network to determine whether elementary frame in which AIS wants to transmit their information is free from transmission of other stations [Stupak et al., 2009]. Only after the positive verification, the device can start their own broadcasting on two dedicated frequencies in the VHF maritime band.

According to ITU-R.M.1371 [ITU, 2010] AIS Class B devices broadcast two messages No. 18 and 19 out of 27 available in AIS system service. Time interval of broadcasted reports is variable and depends on the speed over ground, changes of the course over ground (COG), and multiple access techniques, as presented in Table 1 [ITU, 2010].

Table 1. Reporting intervals for equipment other than Class A shipborne mobile equipment [source: ITU, 2010]

Platform's condition	Nominal reporting interval
AIS Class B, algorithm SOTDMA, SOG ≤ 2 knots	180 s
AIS Class B, algorithm SOTDMA, SOG ∈(2 ÷ 14] knots	30 s
AIS Class B, algorithm SOTDMA, SOG ∈(14 ÷ 23] knots	15 s
AIS Class B, algorithm SOTDMA, SOG > 23 knots	5 s
Search and rescue (SAR) aircrafts (airborne mobile equipment)	10 s
Aids to navigation	180 s
AIS Class B, algorithm CSDMA, SOG ≤ 2 knots	180 s
AIS Class B, algorithm CSDMA, SOG > 2 knots	30 s
AIS base station	10 s

Static and dynamic information contained in the system message No. 18 is the perfect complement to radar information. AIS thus offers access to information for maritime transport in a continuous, reliable and credible manner. In addition, the AIS is an excellent source of information for the purposes of safety systems and vessel traffic management systems in terms of collision avoidance situations. Currently, parametric evaluation of AIS Class B in improving safety of navigation is speculative and navigational knowledge of the AIS characteristics in terms of information provided by the Class B service system is incomplete [Jaskólski, 2013]. In addition, the position criterion as a criterion for parametric evaluation of systems becomes of secondary importance. Parametric assessment was carried out using the criterion of reliability to evaluate AIS in terms of information conveyed affecting the safety of maritime transport. By this date, studies on the availability of data obtained from AIS Class B receivers were conducted at Gdynia Maritime University, and the results were presented in [PN-77/N-04005]. Characteristics of AIS service availability will be conducted on the basis of the data recorded in the laboratory of the Institute of Navigation and Maritime Hydrography from on-board AIS Class B in area of the VTS ZATOKA.

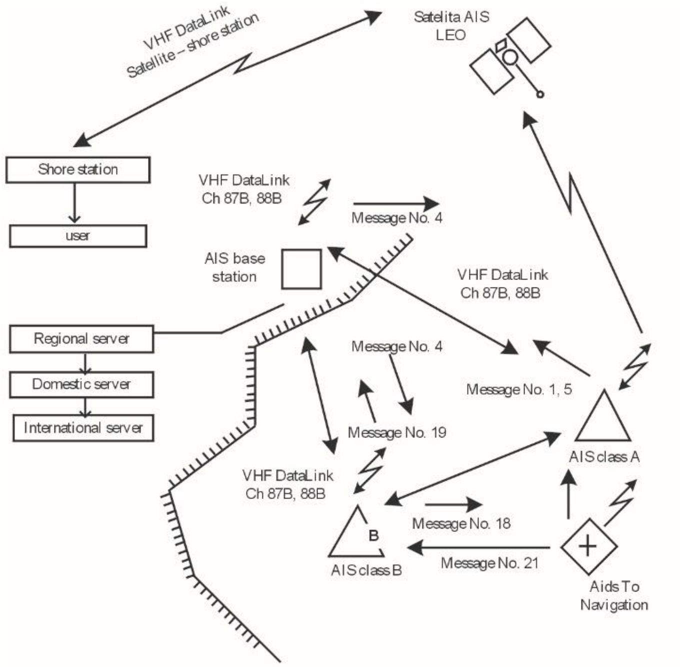

Fig. 1. The concept of AIS operation [source: own study]

DEFINITION OF AIS SERVICE AVAILABILITY

The failure of the navigation system can be treated as a state when the system does not meet the requirements established in accordance with its intended purpose. This means that the failure of the system can be considered as a condition that results from the damage to the internal or external components such as a radio link failure (high levels of noise relative to the level of the useful signal) [Jaskólski, 2014a; Jaskólski, 2014b]. Such a system status can be determined by Time To Repair (TTR) [Specht, 2003]. According to [IALA, 1989] the average value of TTR can be used to estimate the availability. Availability can be assessed by the availability factor *A*, which is the quotient of the average time when the system is available per the total time taken into consideration for the model renewal.

$$A = \frac{MTBF}{MTBF+MTTR}, \tag{1}$$

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

If we consider the navigational structure of the system, as an object performing defined tasks in time, then the process of operation of the system consists of alternated intervals of operating time (up time) T_1, T_2, T_3, ... T_n, understood as moments of proper work and intervals of fault time η_1, η_2, η_3, ... η_n understood as moments of time to restoration. Moments $t'_r = T_1 + \eta_1 + T_2 + \eta_2 + ... + T_{r-1} + \eta_{r-1} + T_r$ is called moments of failures of the system, and $t''_r = t'_r + \eta_r$ are moments of renewal [Felski, et al., 2015; Korzan, 1989]. It was assumed that time intervals T_n and η_n are independent, positive random variables with known probability distributions. Working state is assigned to the binary 1. A state of failure is assigned to binary 0. A graphical representation of the availability of position reports from Class B devices is a renewal model in the form of a two-state stochastic process $X(t)$, $t \geq 0$. The model was presented in Figure 2.

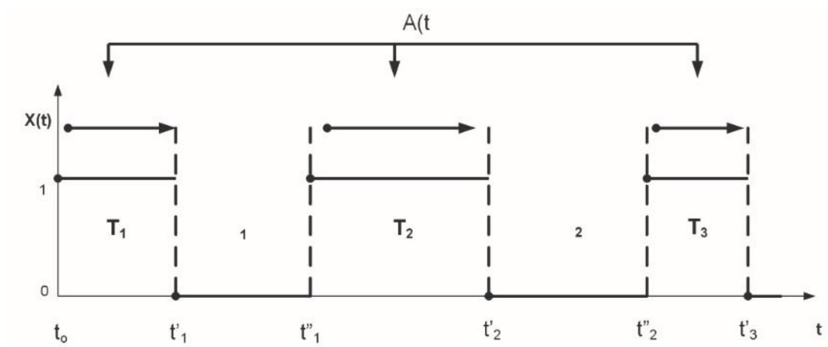

Fig. 2. Graphic presentation of Availability of the system [source: B. Korzan, 1989]

where:
T_n — working time;
η_n — failure time;
$X(t)$ — stochastic process;
t'_r — moments of failure;
t''_r — moments of renewal.

If

$$MTBF = \frac{T_1+T_2+T_3+\ldots+T_n}{n}; \tag{2}$$

$$MTTR = \frac{\eta_1+\eta_2+\eta_3+\ldots+\eta_n}{n} \tag{3}$$

Then we obtain:

$$A = \frac{\frac{T_1+T_2+T_3+\ldots+T_n}{n}}{\frac{T_1+T_2+T_3+\ldots+T_n}{n}+\frac{\eta_1+\eta_2+\eta_3+\ldots+\eta_n}{n}}. \tag{4}$$

Thus:

$$\frac{T_1+T_2+T_3+\ldots+T_n}{n} \rightarrow E(T_n); \tag{5}$$

$$\frac{\eta_1+\eta_2+\eta_3+\ldots+\eta_n}{n} \rightarrow E(\eta_n), \tag{6}$$

where:
$E(T_n)$ — expected value of working time;
$E(\eta_n)$ — expected value of time of failure.

Finally:

$$A = \frac{E(T_n)}{E(T_n)+E(\eta_n)}. \tag{7}$$

Availability of AIS binary data can refer to the interval of successively received position reports from the same station, in the coverage area of the system. Representation of the availability is its limit probability defined as the availability coefficient — A, or according to [PN-77 / N-04005] as an asymptotic availability.

Thus:

$$A = \lim_{t\rightarrow\infty} A(t) = \lim_{t\rightarrow\infty} \frac{1}{E(T_n)+E(\eta_n)} \int_0^{\infty}[1-F(u)]du, \tag{8}$$

where:

$$\int_0^{\infty}[1-F(u)]du = E(T_n) \tag{9}$$

and:
$\int_0^\infty [1 - F(u)]du$ — reliability function [Korzan, 1989].

Discussed system — AIS can be represented as the exponential distribution of residence times of the operating and failure state [Jaskólski, 2014b]. Availability of AIS binary data has an exponential distribution if the density function for the random variable T — Time To Failure (TTF) is shown the relation [Specht, 2003]:

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

Cumulative distribution function of the random variable T (TTF) is [Specht, 2003]:

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

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

where:
λ — failure rate;
μ — repair rate.

In accordance with the properties of the exponential distribution:

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

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

where:
$E_{\exp}(T_n)$ — expected value of the exponential life distribution;
$E_{\exp}(\eta_n)$ — expected value of the exponential failure distribution.

Finally, the following formula is obtained:

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

where:

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

THE STRUCTURE OF THE AIS AVAILABILITY — DEFINING RESEARCH OBJECT

AIS reliability structure can be defined by means of the interval between two consecutive position reports (Message No. 18) from the same AIS Class B unit. This will decide about its state in at any time *t*. For binary objects in terms of reliability model in the form of a digital stochastic process is assumed i.e. $X(t)$, $t \in [0, \tau\}$. The initial assumption was that $X(t)$ would be binary representation of availability process.

$$X(t) = \begin{cases} 1, & t''_n \le t < t'_{n+1} \\ 0 & t'_{n+1} < t \le t''_{n+1} \end{cases} \quad for{:}\, n = 0,1,2,\ldots N, \tag{16}$$

where:

$X(t)$ — two-state stochastic process;

n — number of moment.

State $X(t) = 1$ means that in moment *t* the interval between two position reports received from the same Class B unit is less than 360 s, if SOG is less than 2 knots or 60 s, if SOG is in the range from 2 to 14 knots or it does not exceed 30 s, if SOG is in the range from 14 to 23 knots or it does not exceed 10 s, if SOG is greater than 23 knots. The system is in the operating state.

State $X(t) = 0$ means that in moment *t* the interval between two position reports received from the same Class B unit is greater than 360 s, if SOG is less than 2 knots, or it exceeds 60 s, if SOG is in the range from 2 to 14 knots or it exceeds 30 s, if SOG is in the range from14 to 23 knots or it exceeds 10 s, if SOG is greater than 23 knots. The system is in failure state.

REGISTRATION OF DATA, OPERATION OF AIS

In order to perform statistical analyzes of recorded messages from AIS the method of post-processing of collected data has been applied. The test stand has been prepared at the Institute of Navigation and Maritime Hydrography of Polish Naval Academy. Data were recorded on a carrier in the form of text files. For data analysis, message No. 18 was used. The recorded data were from August and September 2014. The scheme of the test is shown in Figure 3.

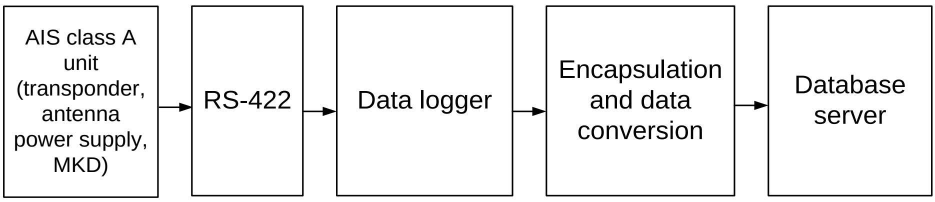

Fig. 3. The onshore station setup of the AIS data acquisition, when MKD — Minimum Keyboard Display

The above configuration allows carrying out the measurement campaign, encapsulation, data conversion to the required form and the storage of data on the server. Subsequently, using the client-server software, it is possible to develop SQL queries to generate information regarding delays of the received messages.

AIS AVAILABILITY ANALYSIS

Studies on the availability of AIS binary data transmission were performed based on the records from AIS Class B in the coverage area of the system. Data registration was conducted from 4 August to 11 September 2014 using SAAB R4 AIS Class A in the laboratory of the Institute of Navigation and Maritime Hydrography. Post-processing method was used in the study. Twenty vessels were selected to estimate the limit probability of availability. According to the Table 1, delay of the received position reports in the system was determined. The values of the delays were the basis for the development of a model of system availability. The database from registered values has 31 724 records from selected vessels equipped with AIS class B unit. The results were presented in Table 2.

According to the assumptions of research methods: failure time η_n and the operating time T_n and the distance from the registration point signals they were sorted according to the number of measurement campaign. Differences in the number of registered records are the result of the residence time of a vessel in the Gulf of Gdańsk, SOG and changes in vessel COG. Moreover, the number of registered records results from multiple access technique used and the radio range determined by the antenna height, AIS transmitter power, antenna system efficiency, the number of vessels in the area.

Table 2. Research outcomes

No of session	**Time of session [s]**	**T_n [s]**	**η_n [s]**	**The distance between AIS class B mobile unit and position of data logging [nautical miles]**		
				max	**min**	**$\bar{X}$**
1	433529	362756	70773	4,1	**0,3**	1,5
2	177983	4420	173563	11,3	6,9	8,8
3	186984	20191	166793	12,9	6,4	8,4
4	386301	379569	6732	5,4	1,0	1,1
5	45294	8679	36615	11,0	1,5	4,5
6	385801	**381917**	3884	3,9	1,5	1,8
7	70437	5014	65423	9,2	4,2	5,4
8	407518	372195	13903	9,4	9,3	9,4
9	255204	42879	212325	12,5	5,8	8,5
10	375717	30340	**345377**	11,2	5,9	8,3
11	282952	**1668**	281284	11,6	1,5	5,7
12	16185	3540	12645	**13,8**	**10,3**	**10,9**
13	39260	10518	28742	12,0	1,0	4,0
14	74982	57776	17206	7,9	0,9	1,6
15	21941	19450	2491	8,3	0,9	5,7
16	92288	37004	55284	11,7	1,5	3,4
17	68062	66838	1224	**2,5**	0,4	**0,7**
18	18168	12613	5555	12,4	5,6	7,6
19	62014	6140	55874	12,6	3,4	6,1
20	12620	11478	**1142**	12,0	1,8	6,4

where:

Tn — operating time [s];

η_n — failure time [s];

$\bar{X}$ — arithmetic mean [nautical miles].

Bold numbers in the Table 2 present the minimum and maximum parameter values. Taking into account the research results of 20 measurement campaigns during 39 days 12 hours 7 minutes and 23 seconds, the system was in operating state in 21 days, 5 hours, 43 minutes and 5 seconds. The system was in failure state if interval between two consecutive AIS position reports received from the same AIS class B unit exceeds twice the value indicated in the Table 1.

Expected value of system lifetime $E_{\exp}(T_n)$ and expected value of system failure time $E_{\exp}(\eta_n)$ for the exponential distribution are presented below:

$$E_{exp}(T_n) = 91749s \qquad E_{exp}(\eta_n) = 77841s.$$

According to reliability theorem, on the basis of $E_{\exp}(T_n)$ and $E_{\exp}(\eta_n)$ tests, it is possible to designate failure rate λ and renewal rate μ. The outcomes for λ and μ for 20 measurement campaign are presented below:

$$\lambda = 0{,}000011\frac{1}{s};$$

$$\mu = 0{,}000013\frac{1}{s}.$$

Finally, we obtain:

$$A_{exp}(t) = 0{,}541.$$

Presented result indicates low availability of binary data obtained from AIS Class B units mounted on non-SOLAS vessels. Limiting value of the availability of binary data transmission from Class A is: $A_{exp}(t) = 0{,}958$. Class A detailed test results for 19 measurement campaigns are presented in [Jaskólski, 2014a]. For example, the graphical representation of unit maneuvering for the 18th measurement campaign is shown in Figure 4. It was observed that the intensity of the different state of the process occurs with increasing distance of the vessel from the registration point signals. Then, the failure of the object occurs in terms of reliability due to the lack of continuity in receiving the message No. 18, in a defined period of time. Total time data-logging for measurement session No. 18 amounted to 122 724 s. The total time between failure of the object amounted to 100 485 s, while the total time to repair the facility amounted to 22258 seconds.

The subject was from the registration point at a distance of 8.48 to 12.05 miles offshore.

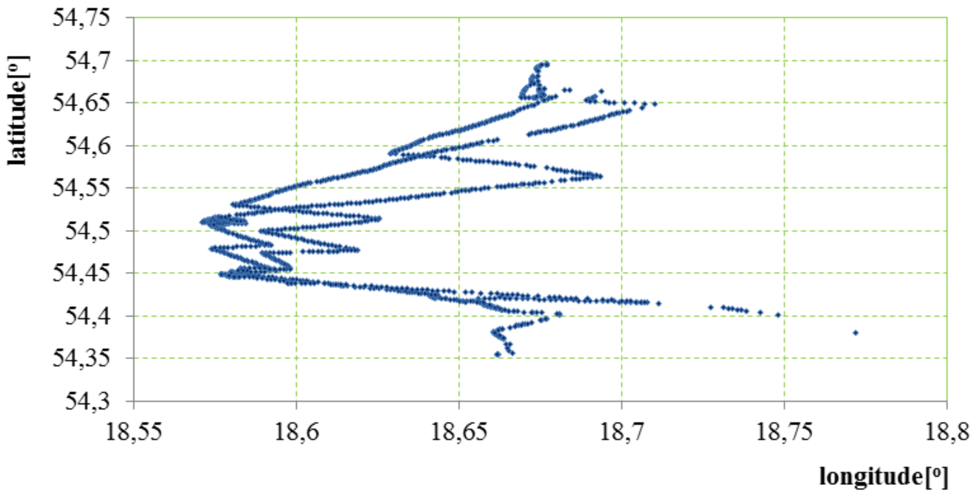

Fig. 4. Maneuvering the ship during data logging; measurement campaign No. 18

This is clearly demonstrated in Figure 5. The Figure shows the dependence of distance ship to data-logging position as a function of campaign time.

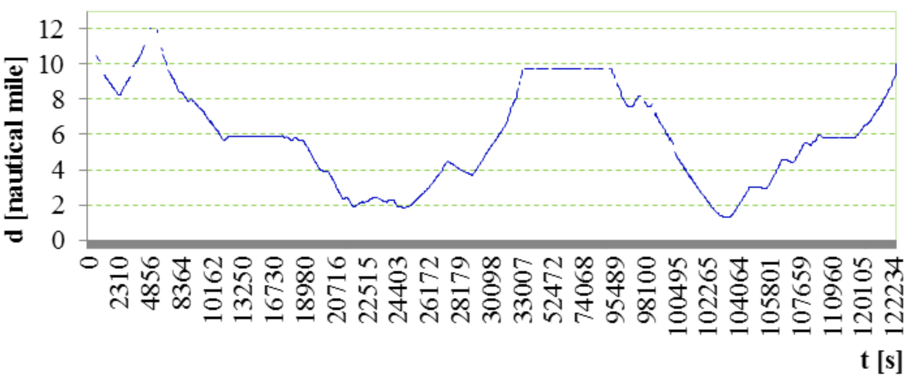

Fig. 5. The distance of the received position reports. Measurement campaign No. 18

However, the intensity between two different states of the process for the renewal model is presented in Figure 6.

Fig. 6. The intensity between failure state ‘0’ and operating state ‘1’
for measurement campaign No. 18

In accordance with measurement campaign No. 18 the system was in operating state in 296 cases. Constancy of this state was recorded in 274 cases and its total duration of selected sessions amounted to 12613 s. This is 69% of all position reports broadcasted by the AIS Class B units. For position: 54,69°N 018,68°E in 76353 sec the latency of position report is 2285 sec (Fig. 7.). Then, the distance to recording point was 9.73 nautical miles. According to model assumptions, the system was in failure state.

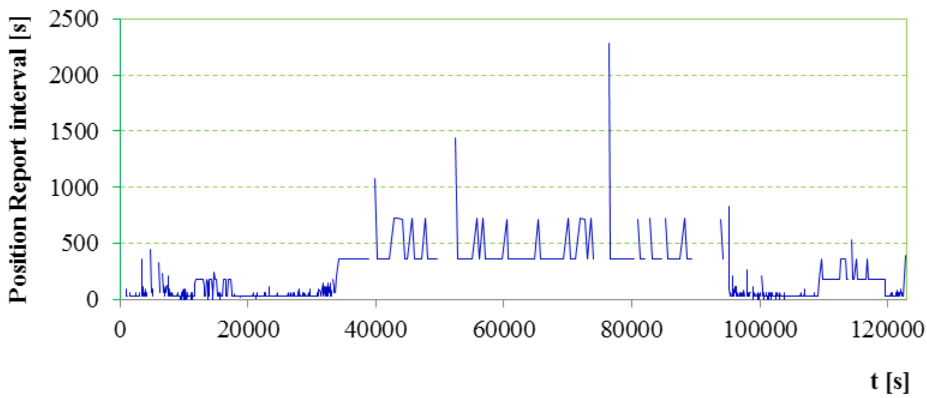

Fig. 7. The interval of position reports; measurement campaign No. 18

Furthermore, on the basis of the measurement campaign, the availability of system binary transmission according to distance has been determined (Fig. 8). The coverage area is limited by radio-horizon, antenna height.

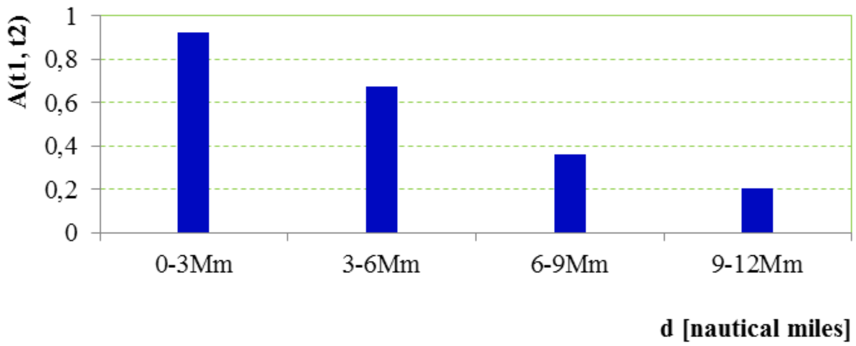

Fig. 8. The availability of binary data transmission in accordance with the distance of AIS class B units, $A(t_1, t_2)$ is mean availability

CONCLUSIONS

Maritime transport plays an important role in the global economy. Executed without ensuring safe conditions poses a risk to human life and the marine environment [Zhang et al., 2015]. For the analysis of safety and risk of maritime transport various methods using multisensory information are applied. For safety analyses information from AIS is used. The information coming from individuals non-SOLAS units performing navigation on inland waters and coastal traffic zone are often overlooked in such situations. This paper presents the results of the availability of information obtained from AIS Class B units installed on the non-SOLAS vessels. Contrary to the Class A, the results demonstrate a low level of availability of information generated from Class B. Availability decreases with distance to the station receiving messages. The mean availability was determined on the basis of data recorded by stationary class A device within 39 days. To determine the performance characteristics of the system registrations only from 20 vessels were selected. The direction of further research should take into consideration the algorithm used to transmit binary data.

REFERENCES

[1] Felski A., Jaskólski K., Application of AIS Position Report to determinate Reliability Positioning Information of DGPS in area of the VTS ‘Gulf of Gdansk’, ‘European Journal of Navigation’, 2014, Vol. 12, No. 1.

[2] Felski A., Jaskólski K., Banyś P., Comprehensive Assessment of Automatic Identification System (AIS) Data Application to Anti-collision Manoeuvring, 'The Journal of Navigation', 68, pp. 697–717, The Royal Institute of Navigation 2015.

[3] IALA, Guide to the Availability and Reliability of Aids to Navigation, International Association of Lighthouse and Aids to Navigation Authorities, 1989.

[4] IMO, STW 42/6, Development of an e-navigation strategy development plan, London 2010.

[5] ITU, Draft Revision of Recommendation ITU-R.M.1371, Technical characteristics for a universal shipborne automatic identification system using time division multiple access in VHF maritime mobile band, 'Radiocommunication Study Groups', International Telecommunication Union, 2010.

[6] Jaskólski K., Availability of AIS binary data transmission based on dynamic measurements performed on The Southern Baltic and The Danish Straits, 'Annual of Navigation', 2013, No. 20, pp. 25–36.

[7] Jaskólski K., The availability of Automatic Identification System (AIS) based on latency position reports in the Gulf of Gdańsk, 'Annual of Navigation', 2014, No. 21, pp. 59–74.

[8] Jaskólski K., Availability and integrity model of Automatic Identification System (AIS) Information, GRIN Publishing GmbH, Munich 2014.

[9] Korzan B., The theory of the reliability [in Polish], WAT, Warszawa 1989.

[10] Specht C., Availability, Reliability and Continuity Model of Differential GPS Transmission, Polish Academy of Sciences, 'Annual of Navigation', 2003, No. 5.

[11] Stupak T., Wawruch R., The investigation of the influence of AIS devices class B on the AIS network [in Polish], 'Works of the Navigational Department of Gdynia Maritime University', 2009, No. 23.

[12] Uriasz J., Determination of ship's safe navigation lane in the navigational information system, 'Annual of Navigation', 2011, No. 17.

[13] Zhang W., Goerlandt F., Montewka J., Kujala P., A method for detecting possible near miss ship collisions from AIS data, 'Ocean Engineering', 1 October 2015, Vol. 107, pp. 60–69, [online], http://dx.doi.org/10.1016/j.oceaneng, [access 04.07.2015].

Received September 2015
Reviewed November 2015

KRZYSZTOF JASKÓLSKI
Polish Naval Academy
k.jaskolski@amw.gdynia.pl

STRESZCZENIE

Problem bezpieczeństwa żeglugi rozważany w aspekcie pomiaru błędu wyznaczenia pozycji wydaje się być rozwiązany w skali globalnej. Istotnego znaczenia nabierają zatem charakterystyki operacyjne systemów radionawigacyjnych i radiokomunikacyjnych, takie jak na przykład dostępność systemu. Zintegrowane systemy nawigacyjne pracują w środowisku multisensorycznym, dlatego też istotne jest szacowanie poprawności w czasie rzeczywistym przesyłanych danych w celu wykorzystania ich w procesie fuzji. W okresie digitalizacji rejestrowanych danych wymagania odnośnie ciągłości, dostępności, niezawodności i wiarygodności informacji stale ulegają zmianie. Artykuł prezentuje problem rozbieżności w odbiorze danych dynamicznych pochodzących z urządzeń AIS klasy B. W związku z powyższym przeprowadzono analizę statystyczną opóźnień w odbiorze raportów pozycyjnych z urządzeń klasy B. Zarejestrowane dane z 82 dni sierpnia, września i października 2014 roku pochodzą z dwudziestu jednostek zlokalizowanych w rejonie odpowiedzialności VTS Zatoka Gdańska. Na podstawie wyznaczonych opóźnień w odbiorze raportów pozycyjnych z urządzeń klasy B istnieje możliwość wyznaczenia dostępności systemu informacyjnego AIS.