

## AVAILABILITY OF AIS BINARY DATA TRANSMISSION BASED ON DYNAMIC MEASUREMENTS PERFORMED ON THE SOUTHERN BALTIC AND THE DANISH STRAITS

### ABSTRACT

The problem of determining coordinates for the requirements of maritime navigation, considered only in terms of measurement error, seems to be solved on a global scale. In view of the above, the operational characteristics of radio navigation systems such as availability are equally important.

This paper analyses the problem of AIS binary transmission availability. An attempt was made to assess the availability of the AIS service transmission channel based on dynamic measurements. For this purpose, the theory of Markov processes defined on a discrete state space was applied. The Criterion of state system availability was adopted, stochastic matrix of probabilities of transitions between the states of the availability and accessibility of states limit the probability of AIS. In this paper, the author proposed a model for the assessment of AIS Service availability. To meet the objective of the research, recorded data derived from the Southern Baltic and Danish Straits Base Stations were used.

### Keywords:

AIS, Markov process, availability.

### INTRODUCTION

Today, the availability of the radio navigation system is one of the main research area of maritime navigation. According to [IALA, 1989] is seen as the probability that an aid or system of aids performs the required functions in the stated

conditions at a specified time. In 1996, the Federal Radio-navigation Plan defines availability as an indicator of the ability of the system to provide usable service within the specified coverage area [FRP, 1996]. In this paper it is proposed to identify the availability of AIS as availability of binary data transmission. Under this assumption, it might be justified to perform studies of the AIS availability based on recorded messages from the laboratory AIS class B receiver mounted on warship ORP 'Wodnik'. AIS signals were registered during the voyage from the 3th to 4th of June 2013 from the base stations, in a range of radio signals. The advantage of these stations in terms of site AIS availability is constant interval time of transmitted messages from these stations.

### **METHODOLOGY OF THE STUDY CONCERNING AIS BINARY TRANSMISSION AVAILABILITY**

On the coasts of the Southern Baltic and the Danish Straits there are located base stations, which signals can be received on the training warship ORP 'Wodnik' during the voyage. One of the conditions to receive messages from base stations is the position of the warship being in the AIS operating range. In the experiment depicted in this paper, the availability of AIS has been studied on the basis of the AIVDM lines, containing the message number 4 (Base Station Report). Analyzed data were recorded on the ORP 'Wodnik', and originate from the base stations in Rozewie, Czołpino, Bornholm, Arkona, Stubenkammer, Svedala, Udby, Kobenhavn, Gilleleje. The specification of base stations is presented in Table 1.

Havig the information on broadcasting antenna height and antenna height of the receiver, the maximum distances have been set between antennas according to the formula:

$$d = 2,08(\sqrt{h_1} + \sqrt{h_2}) \text{ [nautical miles]}. \quad (1)$$

where:

$h_1$  — AIS broadcasting antenna height;

$h_2$  — antenna height of the receiver.

Table 1. Information concerning base stations used in the study with regard to the availability of AIS [own study]

| station name        | latitude  | longitude  | MMSI number | antenna height [m] | Range [nautical miles] |
|---------------------|-----------|------------|-------------|--------------------|------------------------|
| AIS signal register | –         | –          | –           | 9                  | –                      |
| Rozewie             | 54°50,0'N | 018°20,2'E | 002611400   | 85                 | 25,4                   |
| Czołpino            | 54°43,2'N | 017°14,6'E | 002614300   | 75                 | 24,2                   |
| Bornholm            | 55°08,9'N | 014°52,7'E | 002190077   | 120                | 29                     |
| Arkona              | 54°40,8'N | 013°25,8'E | 002112701   | 110                | 28,1                   |
| Stubben Kammer      | 54°34,5'N | 013°39,8'E | 002112705   | 110                | 28,1                   |
| Svedala             | 55°28,7'N | 013°16,2'E | 002655135   | 115                | 28,5                   |
| Udby                | 55°03,1'N | 011°59,3'E | 002190051   | 180                | 34                     |
| Kobenhavn           | 55°41,8'N | 012°36,8'E | 002190047   | 83                 | 25,2                   |
| Gilleleje           | 56°04,7'N | 012°07,8'E | 002190048   | 35                 | 18                     |

Provided the base stations were in a range of radio signals, it was possible to receive AIS messages.

According to [ITU RM1371, 2010] base station transmits the message No. 4 with a fixed 10 seconds time interval. This message contains detailed information about time (year, month, day, hour, minute, second UTC) and MMSI (Maritime Mobile Service Identity) number that identifies the base station. It is possible to create database queries based on these data. Database contains recordings of measurements in 10 seconds intervals. Queries to the database are designed to give an answer how many times per 10 seconds the receiver will record information from base stations (Fig. 1). If one register 1 communication in 10 seconds from one base station, it means the value of the transmission channel availability will be in operating state.

Figures 2 and 3 present the locations of AIS base stations, the numbers concerned MMSI of the base stations, and the time and date presented in boxes concerned the time of start (blue points) and finish (red points) of broadcasting AIS binary data from base stations. Red dotted line and red points concerned the moment of the failure state of AIS binary transmissions.

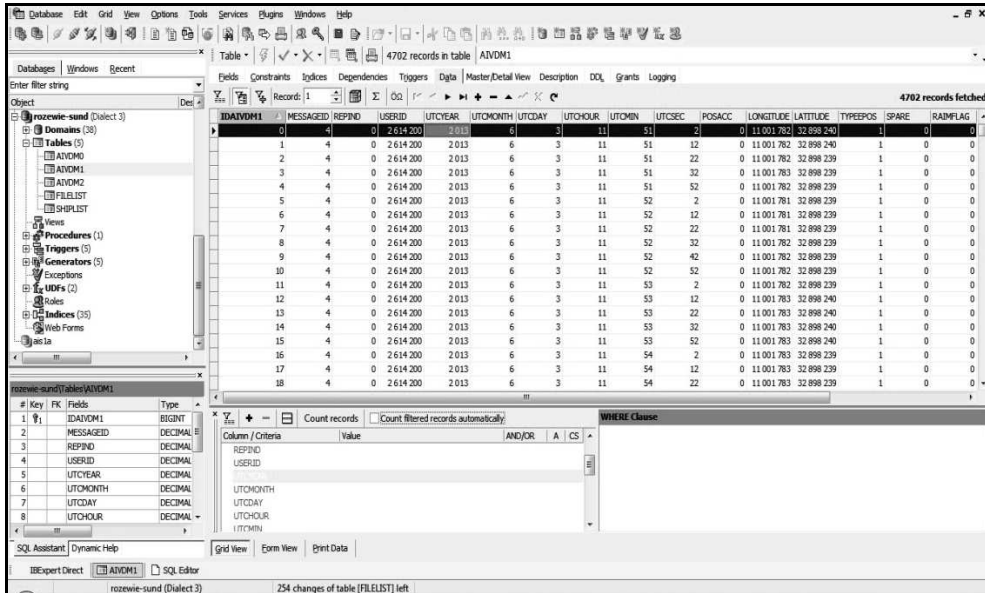


Fig. 1. IB Expert database with recrods in 10 seconds intervals [own study]

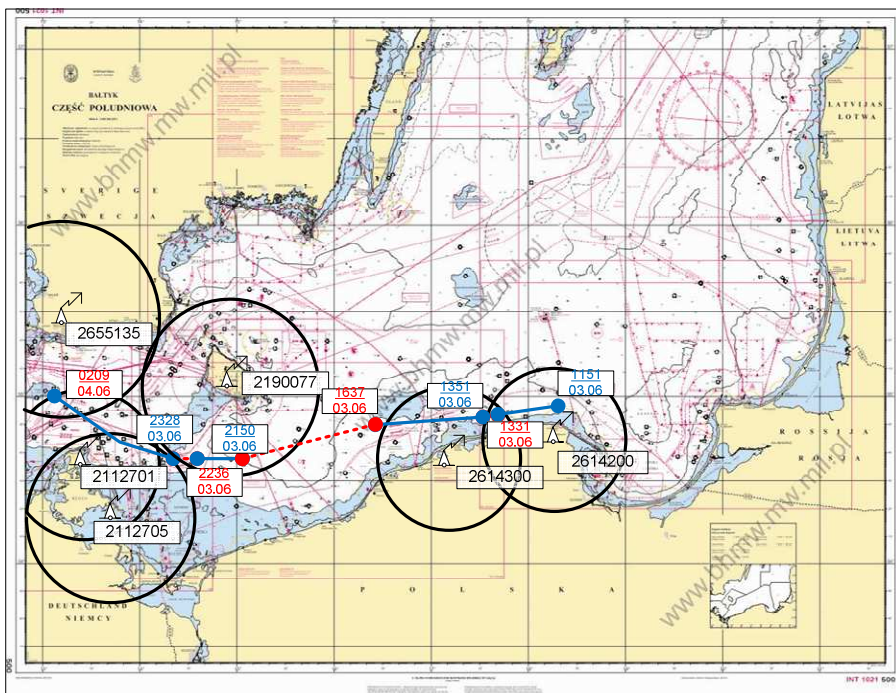


Fig. 2. Positions of the receiver and broadcasting station on the Southern Baltic [own study; chart: BHMW, 2007]

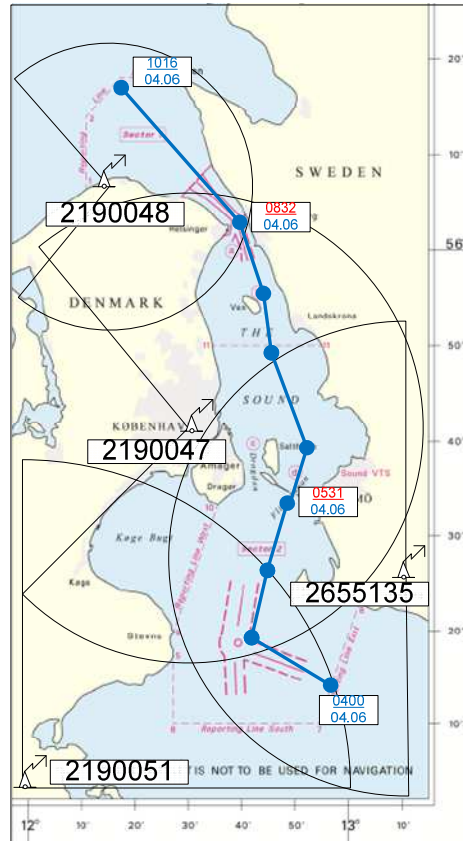


Fig. 3. Positions of the receiver and broadcasting stations on the Baltic Straits (Sund)  
[own study]

In order to define the availability of binary data transmission from AIS base station, operating in the AIS message No. 4 mode, it is critical to determine a decision criterion with regard to system operating state. The decision criterion is as follows: the system transmitting message no. 4 is available if the interval between the following messages received from base stations is not greater than 10 seconds. For this purpose, the author has defined availability of AIS binary transmission as: the time percentage of set interval, in which message No. 4 transmitted by base station in binary mode would be received by the system users within the required interval of 10 seconds, for any position within the operating zone.

## SUMMARY OF THE LATENCY OF AIS BINARY TRANSMISSIONS

The study was performed on recorded data from the period of time between 3 June 2013 and 4 June 2013 (5929 recorded AIVDM lines) on the board of ORP 'Wodnik' during the voyage in the area of The Southern Baltic and The Danish Straits, using AIS Class B receiver, which gives rise to comparisons of possible latency of received signals.

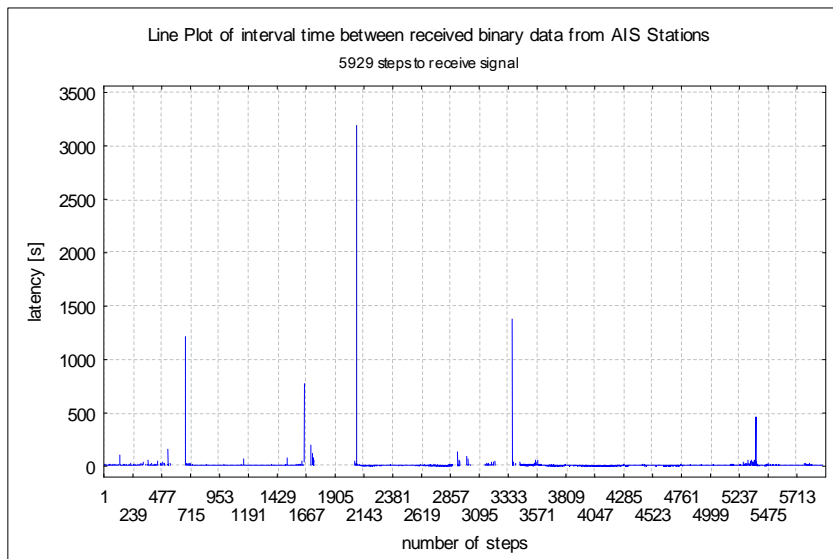


Fig. 4. Latency in received binary data from AIS Base Stations [own study]

On the basis of the signals recorded from base stations maximum latency of received binary messages was specified for the position ranging from 55,14909°N, 014,87911°E to 54,57198°N, 013,65811°E, amounting to 3121 seconds. The condition to specify latency of received messages from AIS base stations was being within the operating zone of the station, which strictly correlates with line-of-sight propagation (radio horizon) of the systems operating within the maritime band V and using surface waves to transmit data. The above research results provide the basis for the development of AIS service availability model. Parametric assessment of availability will be dependant on recorded information from base stations in constant intervals.

**AVAILABILITY MODEL  
FOR THE AIS DATA TRANSMISSION CHANNEL**

Markov processes provide a convenient mathematical apparatus enabling the description and investigation of actual random processes. They are an important class of stochastic processes, which allows a mathematical description of the change of random quantities in time [Grabski F., Jaźwiński J., 2009]. Therefore, the author developed a model of AIS availability using Markov chains methodology.

*Model assumptions:*

Stochastic process is denoted by the symbol:

$$\{X(t) : t \in T\}. \quad (2)$$

Special case of the stochastic process is a random sequence  $\{X_n : n \in (0,1,2,3,\dots,n)\}$  called a random chain. The values of random variables  $\{X_n : n = 0,1,2,3,\dots,5927\}$  represent states of AIS binary transmission availability. Nature of state changes can be assumed  $\{X_n : n = 0,1,2,3,\dots,5927\}$  is Markov chain on set of states  $S = \{S_1, S_2\}$ , where:

- $S_1$  — indicates the probability of received message 4 from AIS Base Station in adequate interval 10 seconds;
- $S_2$  — indicates the probability of received message 4 from AIS Base Station within the interval exceeding 10 seconds.

The residence time moments in the failure state are moments of renewal navigational structure.

From the definition of the Markov Chain it is known that the Markov Chain is characterized by the fact that the state at time  $n + 1$  depends only on state at the time  $n$ , and is independent from the state in the preceding moments [Grabski F., Jadźwiński J., 2009].

The Markov Chain is defined if the initial distribution:

$$P(X_0 = i) = p_i, i \in S \quad (3)$$

and matrix of transition probabilities:

$$P = [p_{ij} : i, j \in S]; \quad (4)$$

$$p_{ij} = P(X_{n+1} = j / X_n = i), n = 0,1,2,3,\dots,5927 \tag{5}$$

are given.

Therefore, the stochastic matrix is being set for the probability of transitions between states of the availability of AIS. Stochastic matrix presents the intensity of transitions between states.

Therefore,  $p_{ij}$  means the probability of transition from the state  $i \in S$  to state  $j \in S$  at  $n + 1$ .

In our case transition matrix has a form:

$$p = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix}. \tag{6}$$

In addition, the initial distribution was adopted to study  $p(0) = [0, 1]$ . It means that the system is in operating state  $S_2$ .

Thus, the matrix of transitions probabilities of Markov Chain takes the following form:

$$p = \begin{bmatrix} 0,7940 & 0,2060 \\ 0,0613 & 0,9387 \end{bmatrix}.$$

Exact distribution of the transition to each state system availability is presented in Table 2 and illustrated in Figure 5. Taking into account the results of research, the system was in operating state in 4568 cases. Constancy of this state was recorded in 4288 cases and its total duration amounted to 11 hours 54 minutes and 40 seconds.

Table 2. Quantitative distribution of transitions between states of the process [own research]

| The transition probabilities of Markov Chain | Number of transitions | The transition probabilities of Markov Chain | Number of transitions |
|--|-----------------------|--|-----------------------|
| $p_{11}$                                     | 1079                  | $p_{21}$                                     | 280                   |
| $p_{12}$                                     | 280                   | $p_{22}$                                     | 4288                  |



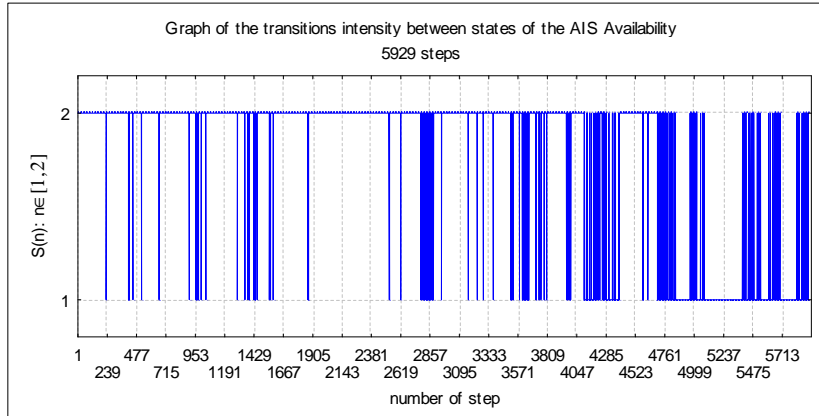


Fig. 5. Graph of the transitions intensity between states of the AIS availability; based on the signals recorded from the base stations in The Southern Baltic and the Danish Straits [own study]

It is easy to calculate the limit probabilities:

$$\lim_{n \rightarrow \infty} p_{ij}(n) = \lim_{n \rightarrow \infty} P(X_{n+1} = j / X_n = i) = \lim_{n \rightarrow \infty} P(X_{n+1} = j) = \pi_j. \quad (7)$$

To achieve this objective one have to solve linear system of equations:

$$\sum_{i \in S} \pi_i p_{ij} = \pi_j, j \in S \quad (8)$$

and

$$\sum_{i \in S} \pi_i = 1, \quad (9)$$

where:

$\pi$  — limit probabilities.

The probabilities  $\pi_1, \pi_2$  constitute the stationary distribution of a homogeneous Markov Chain  $\pi = [\pi_1, \pi_2]$  with transition probability matrix  $P = p_{ij} : i, j \in S$ .

The limit probability is calculated by solving the system of equations based on the product matrix:

$$[\pi_1 \pi_2] \cdot \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} = [\pi_1, \pi_2]. \quad (10)$$

Therefore, one obtain a system of linear equations:

$$\begin{aligned} p_{11}\pi_1 + p_{21}\pi_2 &= \pi_1 \\ p_{12}\pi_2 + p_{22}\pi_2 &= \pi_2 \cdot \\ \pi_1 + \pi_2 &= 1 \end{aligned} \tag{11}$$

Thus, after solving equations one obtain:

$$\begin{aligned} \pi_1 &\cong \frac{3130}{23733}; \\ \pi_2 &\cong \frac{20603}{23733}. \end{aligned}$$

Thus, the probability of the system in operating state  $S_2$  is 0.8681, while in the  $S_1$  state the probability of failure is at the level of 0.1319.

In comparison to static measurements carried out in laboratory of Institute of Navigation and Hydrography and presented in [Jaskólski K., 2011] dynamic scores of limit probabilities indicate slight deterioration of availability service. For the static measurements the system in operating state  $S_2$  was at the level of 0.9273, in the while in the  $S_1$  state, the probability of failure was at the level of 0.0727. Possibly, the difference is connected to limit of the immutable elements. Number of base stations in the area does not change, their antennas are located at fixed altitudes and are arranged in the same places. The scores of limit probability of static and dynamic measurements are presented on the Figure 6.

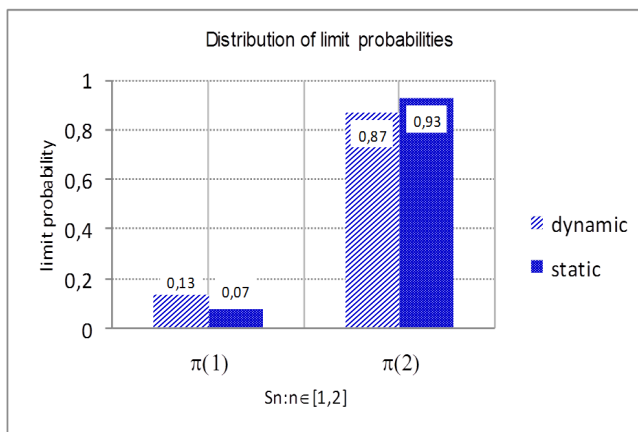


Fig. 6. Limits of probabilities distribution channel concerning availability of AIS data (static and dynamic measurements) [own study]

## CONCLUSION

Twenty-two-hour recording of Number 4 messages originating from the base stations in area of the Southern Baltic and the Danish Straits have been used to study the availability of the data transmission channel. Availability of data transmission channel was measured with intervals of 10 seconds. The level of availability classified AIS to the failure state (level 1) in 1359 cases. Application of the theory of Markov processes concerning operation of technical objects allows to determine the probability matrix of the system state change, which can be observed as the intensity of transitions between states. It can be observed that operating state 2 is prevailing. Determining the probability limits indicates a high probability of occurrence of the state 2. In addition, minimal difference in research results of static and dynamic investigations of ais service availability was observed. The use of Markov Chains is only one example of the methods for parametric assesment of radio navigation systems.

## REFERENCES

- [1] 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, Interenational Telecommuniction Union, 2010.
- [2] Felski A., Grabski F., Specht C., An analytical method of the DGPS Radio-beacon signal Availability Prediction, Annual of Navigation, 1999, No. 1.
- [3] Felski A., Jaskólski K., Analysis of AIS availability (in Polish), Scientific Papers PNA Gdynia 2011.
- [4] Federal Radionavigation Plan, DoD/DoT, Springfield, 1996.
- [5] Grabski F., Mathematics, Mathematical bases of research operations (in Polish), PNA, Gdynia 1981.
- [6] Grabski F., Jaźwiński J., The functions of random arguments of reliability, security and logistics issues (in Polish), WKŁ, Warszawa 2009.
- [7] Hori A., Arai Y., Okuda S., Fujie S., Reliability and Availability on Onboard AIS Information, Proceedings IAIN 2009, Stockholm 2009.

- [8] IALA, Guide to the Availability and Reliability of Aids to Navigation, 1989.
- [9] Jaskólski K., Application of Markov Chains to Analyse the AIS Availability, Annual of Navigation, 2011, No. 18.
- [10] Specht C., Availability, Reliability and Continuity in Navigation and Hydrography — terminology discussion, Annual of Navigation, 2002, No. 4.
- [11] Specht C., Availability, Reliability and Continuity Model of Differential GPS Transmission, Annual of Navigation, 2003, No. 5.

Received September 2013

Reviewed November 2013

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**STRESZCZENIE**

Dokładności, jakie zapewniają współczesne systemy satelitarne, sprawiają, że problem wyznaczania współrzędnych pozycji dla celów żeglugi morskiej w kategoriach minimalizacji błędów pomiaru wydaje się być rozwiązany w skali globalnej. Wobec powyższego równie ważna staje się operacyjna charakterystyka systemów radionawigacyjnych w oparciu o takie wielkości, jak na przykład dostępność.

W artykule przedstawiono analizę zagadnienia dostępności transmisji binarnej w systemie AIS. Badania przeprowadzono dla oszacowania dostępności kanału transmisji AIS w oparciu o pomiary z obiektu ruchomego. W tym celu zastosowano teorię procesów Markova zdefiniowanych na dyskretnej przestrzeni stanów. Adaptowano kryterium stanu dostępności systemu opisane stochastyczną macierzą prawdopodobieństw przejść między stanami. Autor zaproponował model dla oszacowania dostępności AIS. Badania wykonano na danych zarejestrowanych na południowym Bałtyku oraz w cieśninach bałtyckich.