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APPLICATION OF MARKOV CHAINS TO ANALYSE THE AIS AVAILABILITY

ABSTRACT

Despite the initial objections, crew members and vessel traffic service staff use automatic identification system in their activities. In the phase of system implementation, inability to receive signals at scheduled time was raised, and evidenced. The research on AIS availability was conducted by the authors in 2006 and the results were presented in [4].

This paper analyses the problem of AIS availability. Availability has been studied from the standpoint of the quality of data transmission channel. An attempt was made to assess the availability of the AIS service transmission channel. 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, author proposed a model for the assessment of AIS Service availability. To meet the objective of the research, recorded data derived from the AIS Base Station HEL were used.

Keywords:
AIS, availability, Markov Chain.

INTRODUCTION

One of the basic requirements of navigation systems is to maintain the efficiency of certain conditions in defined time. This feature is called the availability. In 1996, the Federal Radio-navigation Plan defines availability as an indication of the ability of the system to provide usable service within the specified coverage area [6]. In this paper it is proposed to identify the availability of AIS as availability of information transmission channel.

Under this assumption, it might be justified to perform studies of the AIS availability based on messages recorded with the receiver. Given the extraordinary volatility conditions, even on a limited area (variable number of vessels, changing their nature, mutual location, etc.) it is proposed to limit 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. Another 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 AVAILABILITY

On the coast of the Gulf of Gdansk there are located three base stations, which signals can be received in Gdynia. 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 in Gdynia, and originate from the base station in Hel, located 9.5 nautical miles away from the place of registration.

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]**
HEL	54°35,9'N	018°48,7'E	002611400	33
AIS signal register	54°32,6'N	018°32,7'E	–	15

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:

$$d = 2{,}08(\sqrt{Kh_1} + \sqrt{Kh_2}) \text{, [nautical miles]} \quad (1)$$

where:
h — antenna height;
K — matching coefficient (refraction) $K = 4/3$.

therefore:

Base station name	**distance from the station to the point of signals registration [nautical miles]**	**d [nautical miles]**
HEL	9,5	16,7

Thus, the base station (Hel) was in a range of radio signals. It is possibble to receive AIS messages.

According to [1] 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 number. That identifies the base station. It is possible to create database queries based on these data. Database contains recordings of measurements in 1-hour intervals. Queries to the database are designed to give an answer how many times per minute the receiver will record information from base stations. If one register 360 communications in one hour from one base station, it means the value of the transmission channel availability will be 100%.

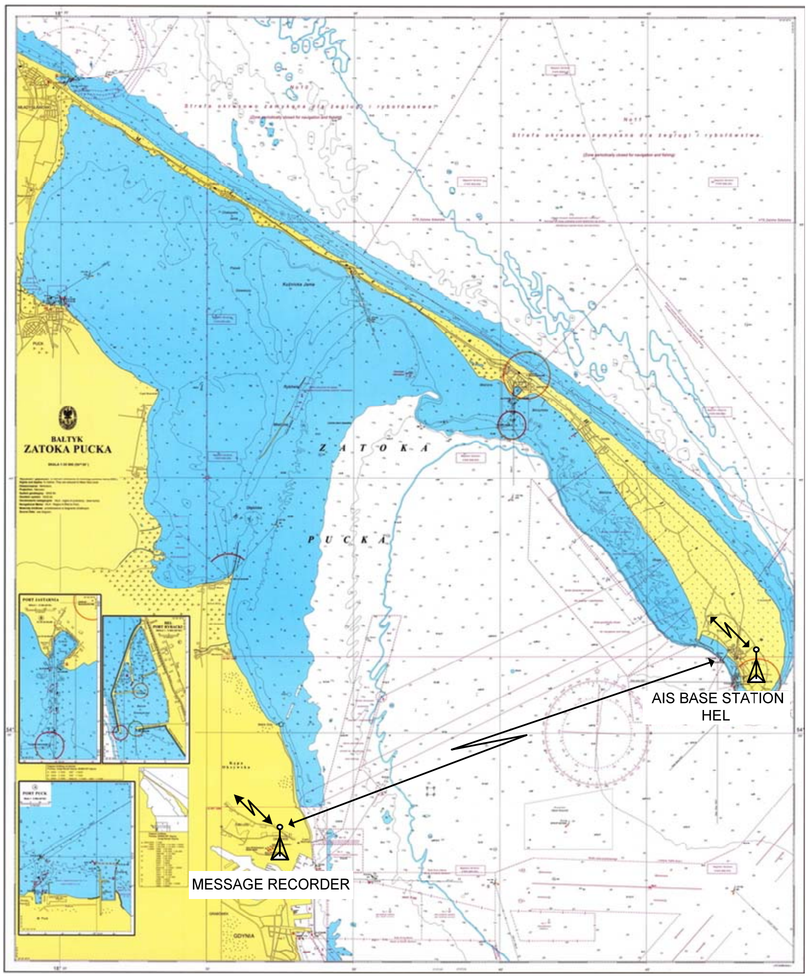

Fig. 1. Location of broadcasting station and the receiver [BHMW, 2007]

The most popular method for determining availability of radio-navigation system availability is the ratio of the Mean Time Between Failure and the sum of MTBF and Mean Time To Repair.

$$A = \frac{MTBF}{MTBF + MTTR} . \qquad (2)$$

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

For the quantitative description of availability, it is possible to accept MTTR (Mean Time To Repair). MTTR can be identified with the expected time of system failure. In this study it was assumed that the MTTR will result from the amount of lack of transmission message 4. When radio signals are broadcasted every 10 seconds, it is possible to determinate MTTR based on the number of messages that have not been received at the scheduled time. It implies MTTR is the average time for the lack of data.

STATISTICAL SUMMARY OF THE AIS DATA TRANSMISSION CHANNEL AVAILABILITY

The study was performed on recorded data from the period of time between 23.12.2010 and 14.03.2011 (selected 54 days — 1296 hours) in the Institute of Navigation and Hydrography laboratory, using SAAB R4 AIS receiver, which gives rise to comparisons of possible variability of these parameters. Only full 24-hour recordings (1-hour interval) of AIS signals are selected for the analysis. Table 2 presents the corresponding coefficients of availability, their minimum and maximum values, expected values, variances, and standard deviations on the basis of statistical analysis based on research results for each 24 hours.

Table 2. Statistical analysis of the studies of AIS availability data transmission channel for every 24 hours based on a 1-hour interval [own study]

DATE	E(X)	V(X)	δ	$E(X)_{max}$	$E(X)_{min}$
2010.12.23	0,9979	6,88E-06	0,002622	1,0000	0,9917
2010.12.24	0,9984	2,63E-06	0,001621	1,0000	0,9944

DATE	E(X)	V(X)	δ	$E(X)_{max}$	$E(X)_{min}$
2010.12.27	0,9965	3,51E-05	0,005921	1,0000	0,9750
2010.12.28	0,9975	3,97E-06	0,001992	1,0000	0,9944
2010.12.29	0,9856	0,001405	0,037489	1,0000	0,8167
2010.12.30	0,9978	5,35E-06	0,002314	1,0000	0,9917
2010.12.31	0,9985	3,34E-06	0,001828	1,0000	0,9944
2011.1.1	0,9983	3,9E-06	0,001975	1,0000	0,9944
2011.1.2	0,9978	6,02E-06	0,002455	1,0000	0,9917
2011.1.3	0,9971	2,92E-05	0,005401	1,0000	0,9750
. . .					
2011.3.11	0,9979	5,54E-06	0,002353	1,0000	0,9917
2011.3.12	0,9978	4,68E-06	0,002164	1,0000	0,9944
2011.3.13	0,9978	5,35E-06	0,002314	1,0000	0,9917
2011.3.14	0,9971	6,36E-06	0,002522	1,0000	0,9917
MEAN VALUE:	0,9965	0,000047	0,004736	1,0000	0,9810

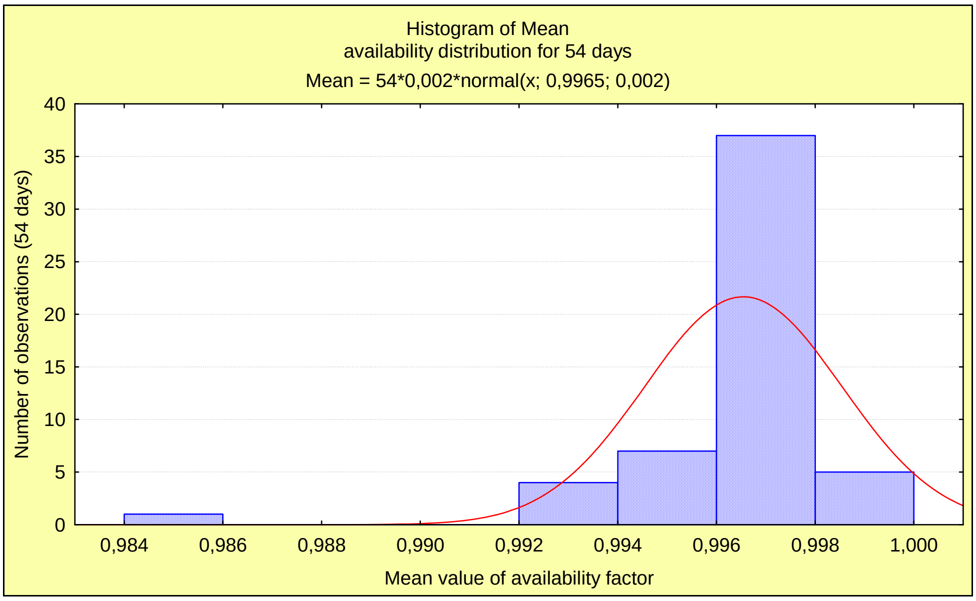

Fig. 2. Histogram of Mean availability distribution [own study]

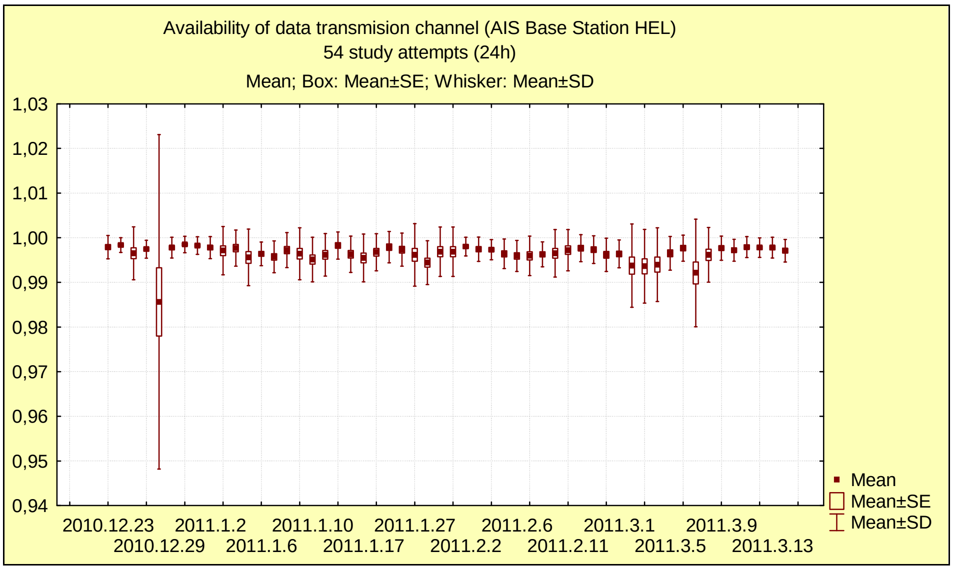

Fig. 3. Graph of changes of AIS availability data transmission channel from the base station HEL [own study]

Taking into account the availability coefficients, mean, maximum and minimum values in 24-hour time interval, have been shown in Figure 2.

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 [8]. Registered number of failures of the system changing over time, changing the availability status of the system in time are values that can be described using stochastic processes. Therefore, the author developed a model of AIS availability using Markov chains methodology.

Model assumptions

Stochastic process denoted by the symbol:

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

Special case of the stochastic process is a random sequence $\{X_n : n \in (0,1,2,3,\ldots,n)\}$ called a random chain. The values of random variables $\{X_n : n = 0,1,2,3,\ldots,1296\}$ represent states of AIS availability. Nature of state changes can be assumed $\{X_n : n = 0,1,2,3,\ldots,1296\}$ is Markov chain on set of states' $S = \{S_1, S_2, S_3\}$,

where:

S_1 — indicates that the availability coefficient is in the range from 0.99 to 1;
S_2 — indicates that the availability coefficient is in the range from 0.95 to 0.99;
S_3 — indicates that the availability coefficient is in the range from 0 to 0.95; the system is in the failure state.

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 [8].

The Markov Chain is defined if the initial distribution:

$$P(X_0 = i) = p_i, i \in S \tag{3}$$

and matrix of transition probabilities:

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

$$p_{ij} = P(X_{n+1} = j / X_n = i), n = 0,1,2,3,\ldots,1296 \tag{5}$$

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:

$$p = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix}. \tag{6}$$

In addition, the initial distribution was adopted to study $p(0) = [1, 0, 0]$. Which means that the system is in operating state S_1.

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

$$p = \begin{bmatrix} 0{,}9441 & 0{,}0543 & 0{,}0016 \\ 0{,}8589 & 0{,}1410 & 0 \\ 0{,}5 & 0{,}5 & 0 \end{bmatrix}.$$

Exact distribution of the transition to each state system availability is presented in Table 3 and illustrated in Figure 3. Taking into account the results of research, high accuracy of the system availability has been observed. The system was capable of fitness in 1216 cases, when the availability coefficient $A(t) \in [0.99, 1]$. Constancy of this state was recorded in 1148 cases and registered in 1296 hours.

Table 3. Quantitative distribution of transitions between different states of the process [own research]

The transition probabilities of Markov Chain	Number of transitions	The transition probabilities of Markov Chain	Number of transitions	The transition probabilities of Markov Chain	Number of transitions
p_{11}	1148	p_{21}	67	p_{31}	1
p_{12}	66	p_{22}	11	p_{32}	1
p_{13}	2	p_{23}	0	p_{33}	0

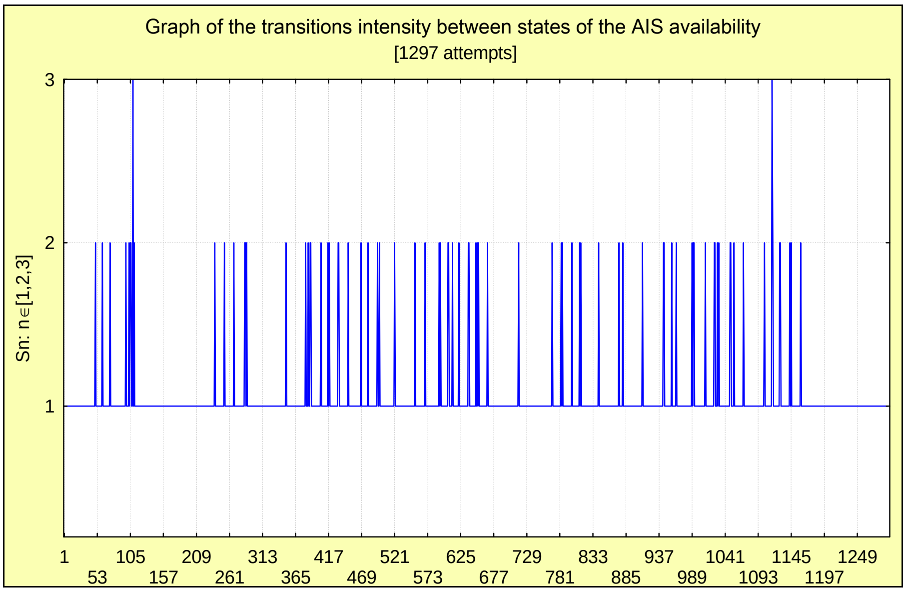

Fig. 4. Graph of the transitions intensity between different states of the AIS availability; based on the signals recorded from the base station HEL [own study]

It is easy to calculate the limit probabilities:

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

To achieve this objective we 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:
π — limit probabilities.

The probabilities π_1, π_2, π_3 constitute the stationary distribution of a homogeneous Markov chain $\pi = [\pi_1, \pi_2, \pi_3]$ 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:

$$\left[\pi_1 \pi_2 \pi_3\right] \cdot \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix} = \left[\pi_1, \pi_2, \pi_3\right] \quad (10)$$

Therefore, we obtain a system of linear equations:

$$\begin{aligned} & p_{11}\pi_1 + p_{21}\pi_2 + p_{31}\pi_3 = \pi_1 \\ & p_{12}\pi_2 + p_{22}\pi_2 + p_{32}\pi_3 = \pi_2 \\ & p_{13}\pi_1 + p_{23}\pi_2 + p_{32}\pi_3 = \pi_3 \\ & \pi_1 + \pi_2 + \pi_3 = 1 \end{aligned} \quad (11)$$

Thus, after solving equations we obtain:

$$\pi_1 \cong \frac{3743125}{4287879};$$

$$\pi_2 \cong \frac{526875}{4287879};$$

$$\pi_1 \cong \frac{17879}{4287879}.$$

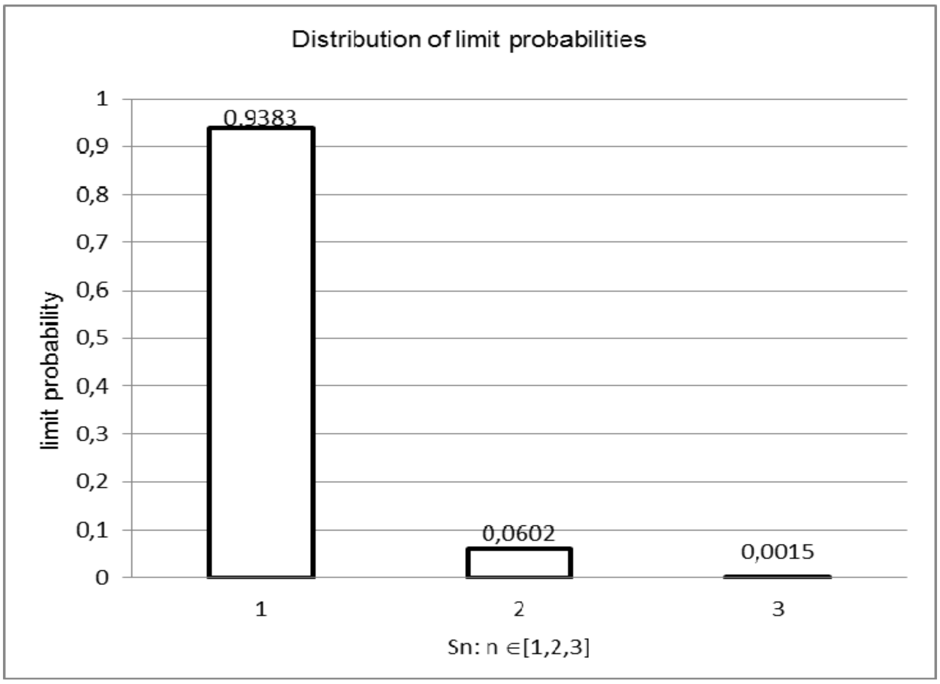

Fig. 5. Limits of probabilities distribution channel concerning availability of AIS data [own study]

Thus, the probability of the system in operating state S_1 is 0.9383, in the intermediate state S_2 is equal 0.0602, while in the S_3 state, the probability of failure is at the level of 0.0015.

CONCLUSION

Twenty-four-hour recordings of Number 4 messages originating from the base station in Hel have been used to study the availability of the data transmission channel. Availability of data transmission channel was measured at intervals of 1-hour. The average expected value for the entire period of data recording $E(X)$ is 0.9965, which indicates a high level of system availability. Minimum level of availability at the time of registration data for the base station HEL amounted to 0.8167 (2010.12.29). The level of availability classified AIS to the failure state (level 3). According to the assumptions in the model studies, this condition probably resulted from the maintenance work carried out in the Gulf of Gdansk. 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 the intensity of transitions between states. It can be observed that states 1(operating state) and 2 are essential states. In addition, state 3 is not reachable from the state 2. Furthermore, the lack of intensity to remain in state 3 can be observed. Probably, this is associated with the temporary unavailability of the system. Determining the probability limits indicate a high probability of occurrence the system in state 1. Additionally, Markov chains offer the possibility to determine the prediction of the system state after n steps. The use of message No. 4 is just one example of the use postprocessing methods to test availability of data transmission channel. It is possible to use other AIS messages.

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