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Crosswise vessel traffic stream as a random disturbing factor of ferry traffic on some waterways in the southern Baltic Sea

Poprzeczny strumień ruchu statków jako losowy czynnik zaburzający strumień ruchu promów na wybranych drogach wodnych południowego Bałtyku

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Key words: vessel traffic, convolution method, random variable, Poisson stream, exponential distribution

Abstract
This article verifies a hypothesis about Poissonian character of vessel traffic stream, disturbing ferry traffic. Based on data from an AIS system, the probability distribution of time between traversing a line of ferry crossing by successive vessels of traffic stream has been determined. Data for four ferry routes in the southern Baltic Sea, have been considered. To test the hypothesis about the form of distribution, the chi square Pearson test has been used.

Słowa kluczowe: ruch statków, metoda splotów, zmienna losowa, strumień Poissona

Abstrakt
Niniejszy artykuł jest prezentacją weryfikacji hipotezy o poissonowskim charakterze strumienia statków, zaburzających ruch promów; na podstawie danych z systemu AIS określono rozkłady prawdopodobieństwa czasu pomiędzy trawersowaniem linii przepraw promowych przez kolejne jednostki strumienia statków; rozpatrzono dane dla czterech przepraw promowych na południowym Bałtyku; wykorzystano test chi kwadrat Pearsona do weryfikacji hipotezy o typie rozkładu.

Introduction

Every day a few hundred vessels move along Southern Baltic waterways. Some of these waterways cross ferry routes connecting Germany with Sweden, Poland with Sweden and Denmark with Sweden. Ferry traffic is generally subordinated to other vessels traffic. Therefore, vessel traffic streams crossing ferry routes are real factors disturbing ferry traffic.

The convolution method is a method of determining vessel traffic intensity with disturbed randomness [1, 2]. In this method the time difference between leaving the fairway section with a disturbance by successive ships is equal to

$$DT = X + (Y_B - Y_A) + (W_B - W_A) + (Z_B - Z_A) \quad (1)$$

where: X – waiting time for the reporting of the successive fairway vessel in undisturbed traffic, Y – time necessary to change vessel traffic parameters, W – time necessary to cover the fairway section with a disturbance, Z – time necessary to reach the full speed.

When vessels report independently and randomly the process of vessel reports theoretically is a Poisson Process [3, 4, 5]. Using data from an Automatic Identification Ships system, a hypothesis about the form of the distribution of the waiting time for the reporting of a successive fairway vessel in undisturbed traffic has been tested. The times of traversing ferry crossing were registered on the following routes:

- Gedser – Rostock,
- Rødbyhavn – Puttgarden,
- Frederikshavn – Göteborg,
- Rønne – Ystad.

The time between traversing the ferry crossing line by successive vessels is a random variable. The form of the probability distribution of this random variable is very important in the convolution method to model a variable X and a variable W (in formula 1).

Traversing Gedser – Rostock route

Times of traversing the ferry crossing line were registered irrespective of the ship movement direction. The subject data set has 36 elements registered 15.02.2010 in the period of time: $18^{00} – 1^{00}$. For 36 ships we have 35 time differences of traversing the ferry crossing.

Using the chi-square goodness-of-fit test [3, 4, 5] and programme *Statistica* we tested the null hypothesis that the form of the distribution of the time between traversing ferry crossing line by successive vessels is:

a) exponential,
b) gamma,
c) lognormal.

a. Testing hypothesis about exponential distribution

The test statistic is equal to 0.09. The p-value (the smallest level of significance that would lead to rejection of the null hypothesis) [2] is very high and equals to 0.765, so we are unable to reject the null hypothesis. Parameter λ of the fitted exponential distribution is equal to 0.08. Data distribution and fitted exponential probability density function are presented in figure 1.

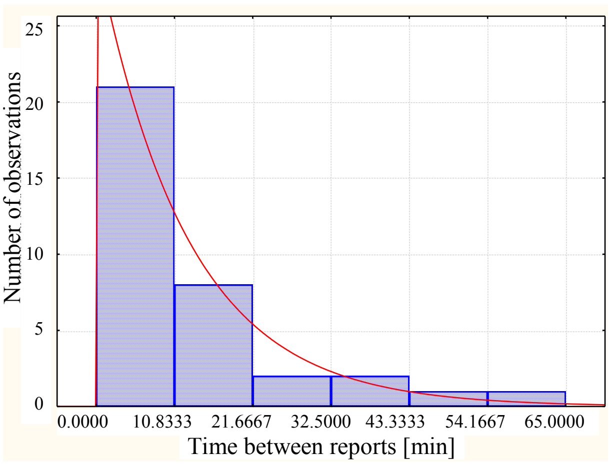

Fig. 1. Time differences in traversing Gedser – Rostock route
Rys. 1. Różnice czasowe w trakcie trawersowania drogi Gedser – Rostock

b. Testing hypothesis about gamma distribution

The test statistic is equal to 1.186. The p-value is equal to 0.276, so we are unable to reject the hypothesis that the time between traversing ferry crossing line by successive vessels has a gamma distribution. There are two parameters of fitted p.d.f.: $r = 11.7$ and $\lambda = 1.08$.

c. Testing hypothesis about lognormal distribution

The test statistic is equal to 1.21. The p-value is equal to 0.27, so we are unable to reject the hypothesis that the time between traversing ferry crossing line by successive vessels has a gamma distribution. There are two parameters of fitted p.d.f.: *mean* = 2 and *variance* = 1.17.

Traversing the Rødbyhavn – Puttgarden route

The subject data set has 36 elements registered 15.02.2010 in the period of time: $17^{00} – 1^{00}$.

a. Testing hypothesis about exponential distribution

The test statistic is equal to 0.355. The p-value is equal to 0.55, so we are unable to reject the null hypothesis. Parameter λ of fitted exponential distribution is equal to 0.07.

b. Testing hypothesis about gamma distribution

The test statistic is equal to 0.713. The p-value is equal to 0.399, so we are unable to reject the hypothesis that the time between traversing ferry crossing line by successive vessels has a gamma distribution. There are two parameters of fitted p.d.f.: $r = 9.64$ and $\lambda = 1.48$. Data distribution and fitted exponential probability density function are presented in figure 2.

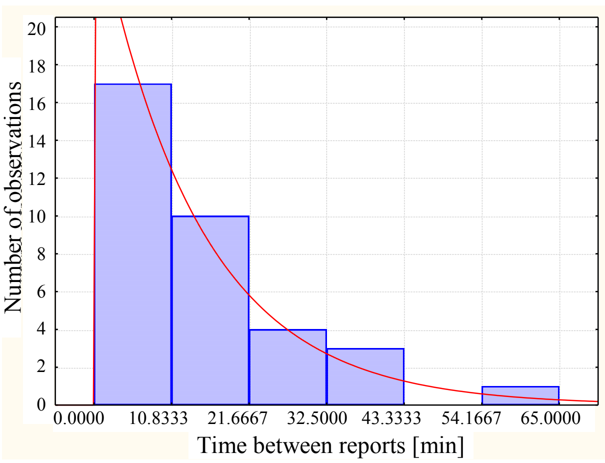

Fig. 2. Time differences in traversing Rødbyhavn – Puttgarden route
Rys. 2. Różnice czasowe w trakcie trawersowania drogi Rødbyhavn – Puttgarden route

c. Testing hypothesis about lognormal distribution

The test statistic is equal to 0.337. The *p*-value is equal to 0.56, so we are unable to reject the hypothesis that the time between traversing ferry crossing line by successive vessels has a gamma distribution. There are two parameters of fitted p.d.f.: *mean* = 2.28 and *variance* = 0.91.

Traversing the Frederikshavn – Göteborg route

The subject data set has 28 elements registered 15.02.2010 in the period of time: $17^{00} – 1^{00}$.

a. Testing hypothesis about exponential distribution

The test statistic is equal to 0.777. The *p*-value is equal to 0.378, so we are unable to reject the null hypothesis. Parameter λ of fitted exponential distribution is equal to 0.066.

b. Testing hypothesis about gamma distribution

The test statistic is equal to 0.79. The *p*-value is equal to 0.374, so we are unable to reject the hypothesis that the time between traversing ferry crossing line by successive vessels has a gamma distribution. There are two parameters of fitted p.d.f.: $r = 15.2$ and $\lambda = 1$.

c. Testing hypothesis about lognormal distribution

The test statistic is equal to 2.43. The *p*-value is equal to 0.12, so we are unable to reject the hypothesis, that the time between traversing ferry crossing line by successive vessels has a gamma distribution. There are two parameters of fitted p.d.f.: *mean* = 2.14 and *variance* = 1.3. Data distribution and fitted exponential probability density function are presented in figure 3.

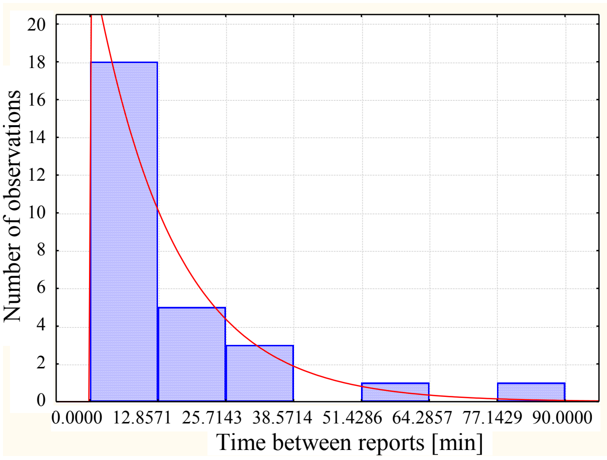

Fig. 3. Time differences in traversing Frederikshavn – Göteborg route
Rys. 3. Różnice czasowe w trakcie trawersowania drogi Frederikshavn – Göteborg

Traversing Rønne – Ystad route

The subject data set has 54 elements registered 20.02.2010 in the period of time: $11^{00} – 24^{00}$.

a. Testing hypothesis about exponential distribution

The test statistic is equal to 2.19. The *p*-value is equal to 0.334, so we are unable to reject the null hypothesis. Parameter λ of fitted exponential distribution is equal to 0.07. Data distribution and fitted exponential probability density function are presented in figure 4.

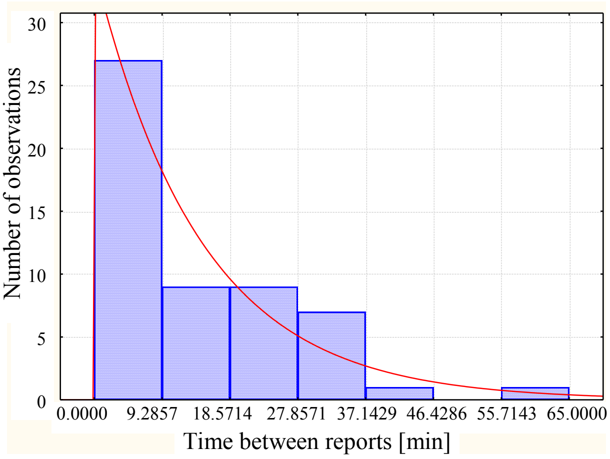

Fig. 4. Time differences in traversing Rønne – Ystad route
Rys. 4. Różnice czasowe w trakcie trawersowania drogi Rønne – Ystad

b. Testing hypothesis about gamma distribution

The test statistic is equal to 6.58. The *p*-value is equal to 0.087, so we are unable to reject the hypothesis that the time between traversing ferry crossing line by successive vessels has a gamma distribution. There are two parameters of fitted p.d.f.: $r = 10.9$ and $\lambda = 1.34$.

c. Testing hypothesis about lognormal distribution

The test statistic is equal to 3.24. The *p*-value is equal to 0.072, so we are unable to reject the hypothesis that the time between traversing ferry crossing line by successive vessels has a gamma distribution (though *p*-value is close to typical significance level $\alpha = 0.05$). There are two parameters of fitted p.d.f.: *mean* = 2.14 and *variance* = 1.3.

Summary

Of seven basic continuous probability distributions (uniform, normal, exponential, gamma, Weibull, lognormal, chi square), three fit well the subject random variable. In all above cases, time between traversing ferry crossing line by successive vessels can be treated as a random variable with exponential as well as gamma as well as lognormal distribution. But the highest *p*-value were for exponential distribution. So the reporting process (irrespective of the ship movement direction) can be treated as a Poisson process. A knowledge about the form of the probability distribution of the ferry traffic disturbing factor can help to manage the ferry traffic.

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