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Gumbel distribution in analysis of vessel speed on the Świnoujście–Szczecin fairway

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Abstract
The present article concerns a problem of vessel speed modeling in restricted areas, where vessel traffic flow is disturbed. In analysis of vessel speed on the Świnoujście–Szczecin fairway, division into the particular ship types has been made. Probability distributions describing speed of different ship groups have been analysed. Using the chi-square goodness-of-fit test it has been showed that the best distribution describing vessel speed of the most ship groups, is the Gumbel distribution.

Introduction

The vessel speed in restricted areas, where a vessel traffic flow isn't too much disturbed, may be described and modeled by normal and lognormal distribution [1, 2]. Whereas the growing disturbances the bigger difference between the speed distribution and the normal distribution [2, 3]. Additionally, the vessel traffic flow isn't homogeneous. Different groups of ships have their own distributions. So, in this article the data set of vessel speed has been divided into 7 types:

– barges;
– tankers;
– containers;
– cargo;
– general cargo;
– carriers;
– other ships.

For particular ship groups, a vessel speed has been analysed on different section of Świnoujście–Szczecin fairway. Data from VTS Szczecin have been used.

Vessel speed distribution on the section 11 km – I Brama Torowa

The section *11 km – I Brama Torowa* is a part of the Świnoujście–Szczecin fairway 5.2 km long. In first half 2009, in the direction north-south, 1034 ships were registered on this section. The following table presents the division of this set into 7 groups.

Table 1. The vessel number of different types on the section *11 km – I Brama Torowa*

No.	Vessel type	Number of vessels
1	Barges	30
2	Tankers	140
3	Containers	73
4	Cargo	500
5	General cargo	184
6	Carriers	69
7	Other ships	38

Speed distribution of barges

Figure 1 presents the frequency histogram and the graph of Gumbel probability density function, fitted to data for barges.

In the chi-square goodness-of-fit test [4], the test statistic is equal to 0.96 alongside the critical value 3.84 (at the 0.05 level of significance). So, we are unable to reject the hypothesis that the speed of barges between reporting points *11 km* and *I Brama Torowa* has a Gumbel distribution. In this case location parameter $\alpha = 9.1$ and scale parameter $\beta = 0.65$.

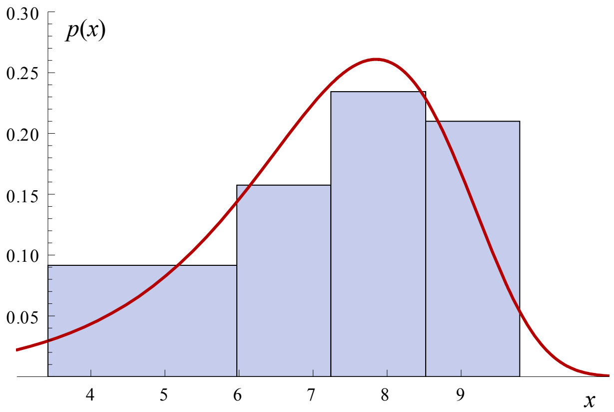

Fig. 1. Frequency histogram of vessel speed for barges

Speed distribution of tankers

Figure 2 presents the frequency histogram of data connected with tankers speeds.

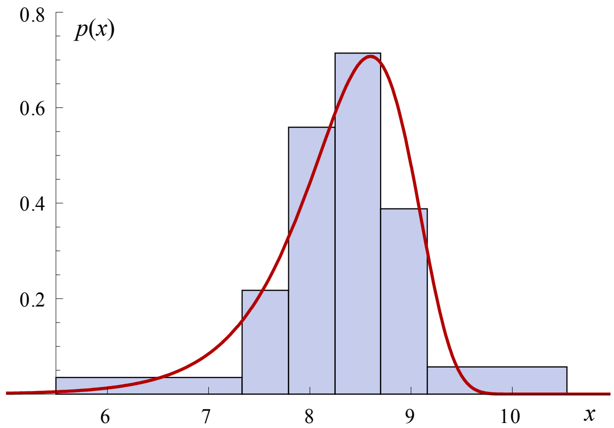

Fig. 2. Frequency histogram of vessel speed for tankers

Using the chi-square goodness-of-fit test we find that the test statistic is equal to 6.53 alongside the critical value 7.8 (at the 0.95 confidence level). So, we are unable to reject the hypothesis that the speed of tankers has a Gumbel distribution. In this case location parameter $\alpha = 8.6$ and scale parameter $\beta = 0.52$.

Speed distribution of containers

Figure 3 presents the histogram and the graph of Gumbel probability density function, fitted to data for containers.

In the chi-square goodness-of-fit test, the test statistic is equal to 6.96 and the test probability $p = 0.03$. So, at the 0.05 level of significance, we must to reject the hypothesis that the speed of containers has a Gumbel distribution. But at the lower significance level we can describe the speed of containers between reporting points *11 km* and *I Brama Torowa* by the Gumbel distribution with parameters $\alpha = 8.8$ and $\beta = 0.54$.

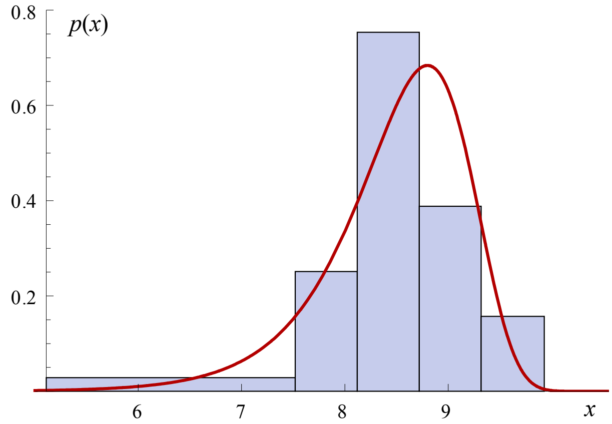

Fig. 3. Frequency histogram of vessel speed for containers

Speed distribution of cargo ships

On the base of chi-square goodness-of-fit test we must to reject the hypothesis that the speed of cargo ships has a Gumbel distribution. Because the test statistic is equal to 33.8 alongside the critical value 14.1 (at the 0.05 level of significance). But using mixed distribution [2, 3], the hypothesis about Gumbel – Uniform distribution of cargo ships speed can be tested. Probability density function in the form presented below describes good speed distribution of cargo ships. In the chi-square goodness-of-fit test, the test statistic is equal to 8.53. This function is the following:

$$f(x) = 0.93\,pdfG(8.72, 0.46) + \\ + 0.07\,pdfU(6.54, 10.55) \quad (1)$$

where

pdfG(a, b) – probability density function of Gumbel distribution with parameters a and b;

pdfU(c, d) – probability density function of Uniform distribution giving values between c and d.

Figure 4 presents the frequency histogram of data connected with cargo ship speeds and fitted pdf of mixed distribution.

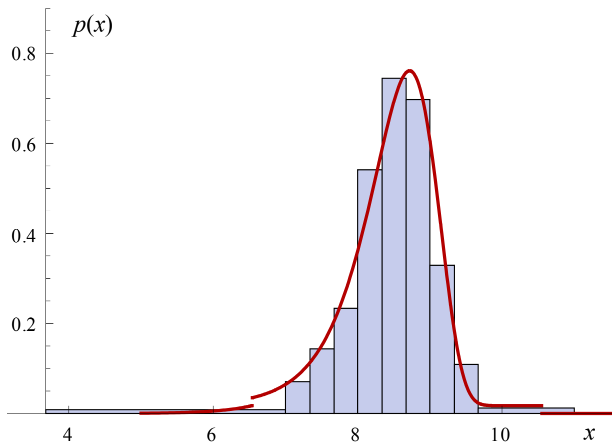

Fig. 4. Frequency histogram of vessel speed for cargo ships

Speed distribution of general cargo ships

Figure 5 presents the frequency histogram and the graph of Gumbel probability density function, fitted to data for general cargo ships.

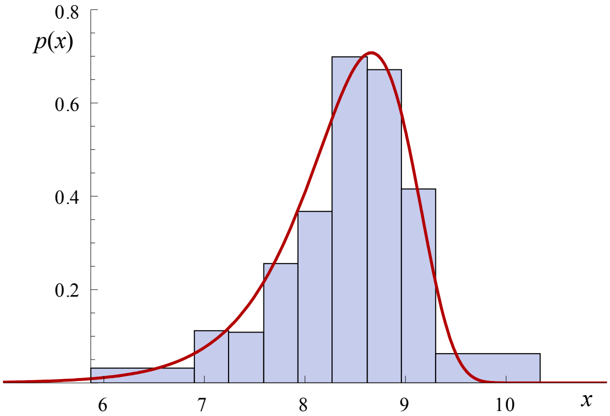

Fig. 5. Frequency histogram of vessel speed for cargo ships

In the chi-square goodness-of-fit test, the test statistic is equal to 9.4 alongside critical value 12.6 (at the 0.95 confidence level). So, we are unable to reject the hypothesis that the speed of general cargo ships between reporting points *11 km* and *I Brama Torowa* has a Gumbel distribution. In this case location parameter $\alpha = 8.66$ and scale parameter $\beta = 0.52$.

Speed distribution of carriers

Figure 6 presents the histogram and the graph of Gumbel probability density function, fitted to data for carriers.

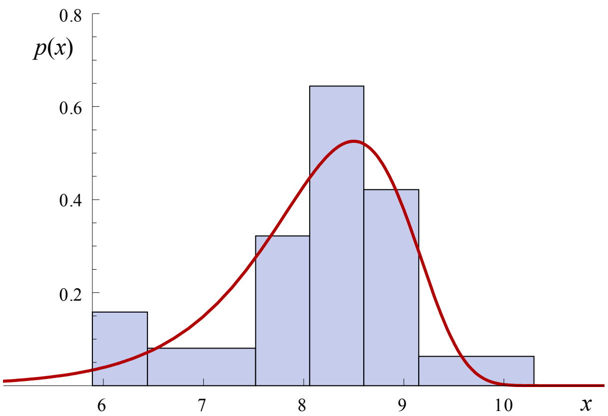

Fig. 6. Frequency histogram of vessel speed for carriers

Using the chi-square goodness-of-fit test we find that the test statistic is equal to 6.06 and test probability $p = 0.11$. So, we are unable to reject the hypothesis that the speed of tankers has a Gumbel distribution. In this case location parameter $\alpha = 8.5$ and scale parameter $\beta = 0.7$.

Speed distribution of other ships

Tugs, factory trawler, research / survey vessel, suction dredger, diving support vessel, ro-ro / passenger ship, fishing vessel and offshore supply ship formed a group called "other ships".

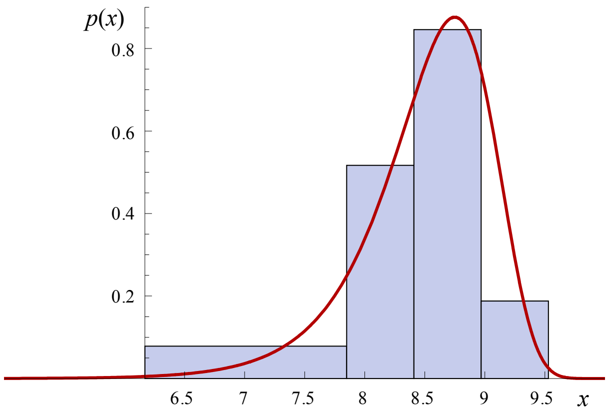

Fig. 7. Histogram of data for other ships

In the chi-square goodness-of-fit test, the test statistic is equal to 1.73 alongside the critical value 3.84 (at the 0.95 confidence level). So, we are unable to reject the hypothesis that the speed of "other ships" between reporting points *11 km* and *I Brama Torowa* has a Gumbel distribution. In this case location parameter $\alpha = 8.75$ and scale parameter $\beta = 0.42$.

Vessel Speed Distribution on other sections

Section Karsibor – Dok5

The section *Karsibor – Dok5* is a part of the Świnoujście–Szczecin fairway 53.7 km long. In first half 2009, in the direction north-south, 752 ships were registered on this section. But 13 vessels had different stoppages on this section. So, the data set used to analyse, had 739 elements. The table 2 presents the division of this set into 7 groups.

Table 2. The vessel number of different types on the section Karsibor – Dok5

No.	Vessel type	Number of vessels
1	Barges	27
2	Tankers	67
3	Containers	69
4	Cargo	366
5	General cargo	134
6	Carriers	49
7	Other ships	27

Like in chapter *Vessel Speed Distribution on the section 11 km – I Brama Torowa*, the testing

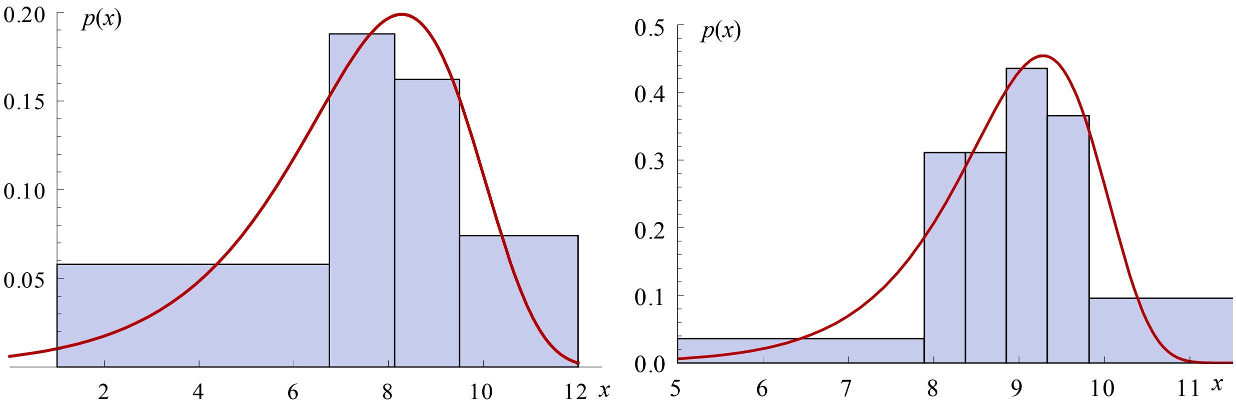

Fig. 8. Frequency histogram of vessel speed for barges and tankers

hypothesis about Gumbel distribution of the vessel speed for separate types of ships has been made. For groups: barges, tankers, containers, general cargo and other ships, we can accept that the vessel speed between reporting points *Karsibor* and *Dok5* has a Gumbel distribution. In figure 8 are presented demonstration histograms with fitted Gumbel pdf.

For cargo ships and carriers mixed distributions have been used.

Section Plawy 13–14 – Krepa Dolna

The section *Plawy13–14 – Krepa Dolna* is a part of the Świnoujście–Szczecin fairway 8.3 km long. On this section, in first half 2009, in the direction north-south 1004 ships were registered and in the opposite direction 1012 ships were registered. For almost all ship types, the hypothesis about a Gumbel distribution of vessel speed has been proved. Below demonstration histograms with fitted Gumbel pdf are presented.

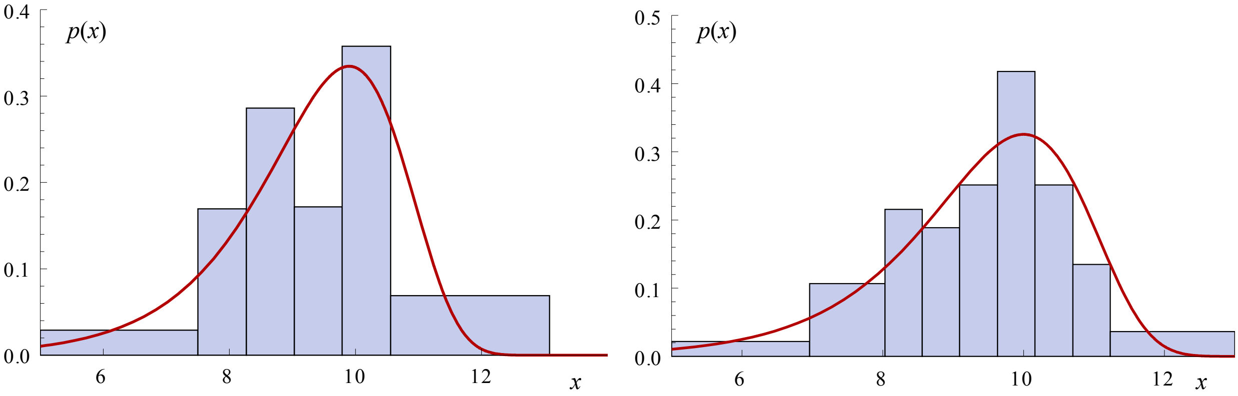

Fig. 9. Frequency histograms of vessel speed for carriers and tankers, direction Świnoujście–Szczecin

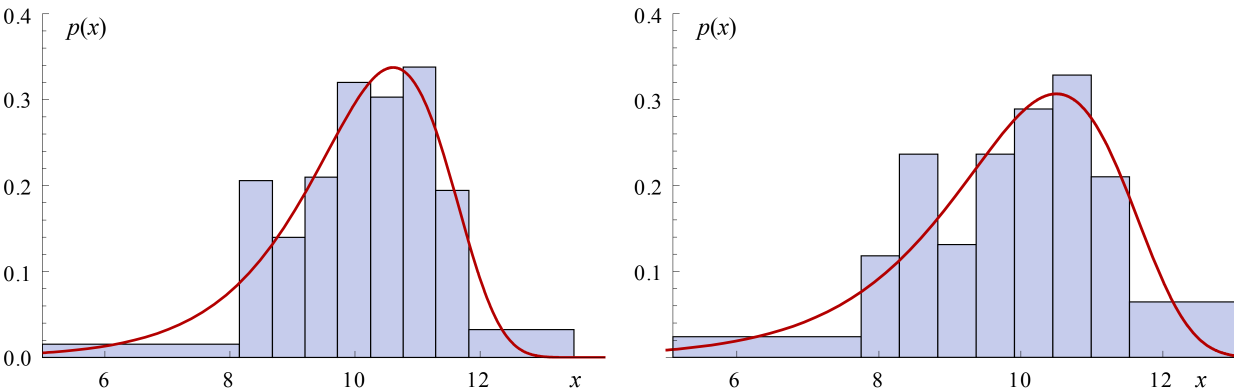

Fig. 10. Frequency histograms of vessel speed for general cargo and tankers, direction Szczecin–Świnoujście

For the vessel speed in opposite direction the hypothesis about a Gumbel distribution was true, too (Fig. 10).

Conclusions

All frequency histograms aren't symmetrical and all have negative coefficients of skewness (a long left tail). The cause of that is the speed limit, what is one of the most important factors disturbing vessel traffic on the Świnoujście–Szczecin fairway. So, the most of presented vessel speed distributions are in accordance with Gumbel distribution. But disagreement with this distribution of some groups (especially cargo ships) results probably from a big diversity inside these groups. And necessary is to do further research on this diversity. Other reasons of this disagreement are other than speed limit restrictions of vessel traffic on the fairway.

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