TOWARDS STATISTICAL CHARACTERISTICS OF TRAFFIC FLOW

Maxim O. Maksimov, Alexander A. Lentarev

The authors present the results of statistical data processing on vessel traffic in different parts of the World Ocean. It is particularly shown that distances abeam between the own ship and neighboring vessels comply with the normal distribution law while the statistically important relation between distances abeam and length of surrounding vessels has not been found. The received results provide additional information on the statistical characteristics of traffic flows and can be used in theoretical and experimental research related to, e.g. vessel traffic modeling in various traffic patterns study.

Keywords: vessel, traffic flows, vessel traffic, vessel flow characteristics, ship-traffic characteristics, distance abeam, distribution function.

In the last decades the world merchant marine fleet had undergone considerable qualitative and quantitative changes that seriously affected the navigation conditions. One of the results of these changes was the fact that in many areas of the World Ocean, especially in places of confluence and intersection of marine trade routes, in straits, narrow channels and approach zones, powerful permanently functioning traffic flows have been formed. In such conditions the usual problems going with navigation, marine casualties in particular become especially critical. All this together with a natural course of scientific-technological progress has caused necessity of carrying out theoretical and experimental works linked to a ship-traffic control. In the result of doing such work, the separate scientific-applied field of knowledge was formed, which in English version got the name "marine traffic engineering" [1]. Traffic flows became one of central subjects of study in this field.

The traffic flow means totality of vessels, moving in one direction along a certain waterway section [2, 3]. Review of numerous publications devoted to this problem (for example, see monograph [4]), shows that concerning traffic flow the following general parameters were studied:

– intensity (number of vessels passing through any water-way section per unit time);

– density (number of vessels located on water-way square unit);

– varieties of an average velocity (momentary average velocity, average velocity at the entrance, average velocity of passing a waterway, etc.);

– composition of traffic flow on length, type and displacement of vessels in this flow;

– traffic flow distribution law, determining the type of such flow;

– distribution of vessels, which form traffic flow, on waterway breadth.

Electronic navigation equipment by which modern vessels are equipped, make it possible to gain additional characteristics of traffic flow which can be useful for theoretical and experimental researches. In the present article an effort is made to gain distribution of beam distances to ambient vessels and to track the dependence of these distances from the length of such vessels.

The necessary statistical information was gathered on m/v "Stolt Gulf Mishref" (length L = 182.8) during her voyage in the waters of South and Southeast Asia. The navigation bridge of this vessel is rigged by various navigation equipment, including ECDIS (Electronic Chart Display and Information System), AIS (Automatic Identification System), radio location station with Automatic Radar Plotting Aids (ARPA) and global positioning system (GPS) Navstar receiver. These systems are integrated in a uniform navigating complex, therefore on ECDIS display, where the own vessel's symbol on GPS Navstar co-ordinates is displayed; it is possible to display information from ARPA and AIS. An example of such information is shown in Fig.1 where the following are shown: a) indication of own vessel (a circle with a velocity vector), proceeding in the given traffic lane, indication of meeting ships; b) indication of ambient vessels (triangles with velocity vectors); c) AIS display screen where the information about m/v "Cape Carnel", «captured» (acquired on automatic tracking), in particular, her coordinates, heading and velocity above the ground, course over the ground, current values of bearing and distance to it, and also time and closest point of approach are presented. Thus, observed statistical data have one limitation: they consider only AIS equipped ambient vessels.

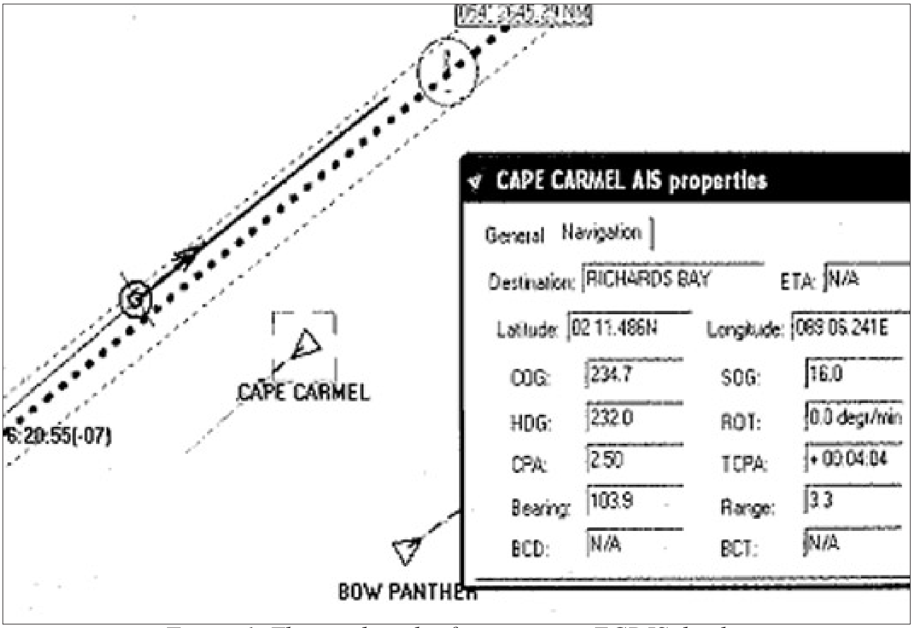

Figure 1. The combined information on ECDIS display

Approximately in 85% cases neighboring vessels steer on the opposite (less - on the same direction) courses and their headings and the heading of own vessel differed for no more than 3° (for meeting ships the heading was corrected at 180°.

If headings of own ship and meeting ship were different, the distance by beam distance was determined by hand method using standard tools of ECDIS or radio location system (ARPA).

We will show the order and estimation results of the statistic data on an example of the analysis of beam distances on a starboard side, observed around the western entry to the Strait of Malacca in March and June, 2012. Totally 102 beam distances were determined according to data of the ship's AIS, which were divided into 10 intervals by magnitude 0.3 cable length (Table 1).

Table 1. Distribution of beam distances

Interval, miles	less than 0.9	0.9 -1.2	1.2 -1.5	1.5 -1.8	1.8 -2.1	2.1 -2.4	2.4 -2.7	2.7 -3.0	3.0 -3.3	more than 3.3
Mean interval, miles	0.75	1.05	1.35	1.65	1.95	2.25	2.55	2.85	3.15	3.45
Nr. of beam distances in interval	3	6	7	13	23	19	11	10	5	5

The analysis of the above statistical sample was carried out using MS Excel in accordance with the Standard on statistical analysis of testing and measurement results [5]. After using the Excel «Descriptive statistics» tool we got the following characteristics of this sample: mean value (results are given with an accuracy to 0.01) – 2.1; median – 2.0; mode – 2.0; standard deviation – 0.67; dispersion – 0.45; excess kurtosis – 0.05; asymmetry – 0.14; reliability level (95.0%) – 0.13.

Figure 2 shows the bar graph of distribution of the beam distances presented in Table 1. Bar chart shape admits possibility of normal distribution. Preliminary estimate bears evidence of legitimacy of this assumption, considering resulted values of excess kurtosis and asymmetry and also that 70.6% of distances are within limits of "the mean, give or take standard deviation" (it is allowed not less than 68%), and 96.9% are within limits of "the mean, give or take duplicated standard deviation" (it is allowed not less than 95%) [5].

To check hypothesis about correspondence of empirical distribution to expected predicted distribution at sample volume n$\geq$100 Pearson criterion-of-fit test χ^2 counted as

$$\chi^2 = \sum \frac{(d_i - np_i)^2}{np_i}, \qquad (1)$$

is often used, where p_i – probability of falling studied random variable in the interval; d_i – observable data (beam distances); np_i – equalizing frequencies matching to theoretical normal distribution. Taking into account a mean d_{cp}=2.1 and standard deviation σ =0.67 theoretical values of number of distances which fall in the relevant have been obtained. These values are in the form of a bar graph also shown in Figure 2.

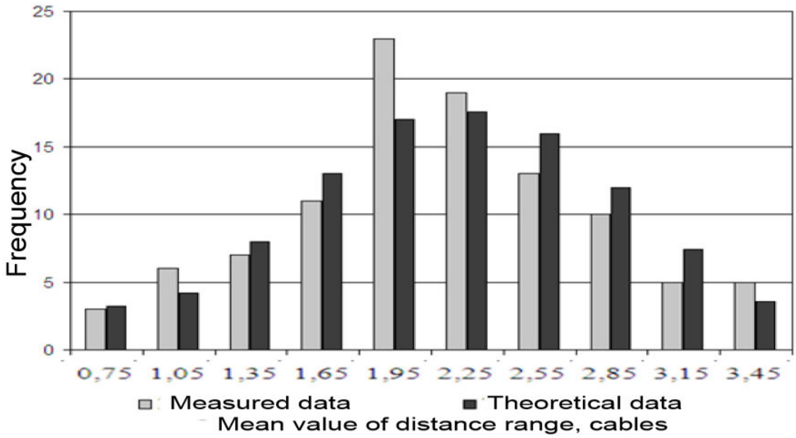

Figure 2. Distribution histogram of beam distances on a starboard side near the western entry to the Strait of Malacca.

For usually applied level of significance α = 95% and number of a degree of freedom k = 7 critical value of criterion will be χ_{α}^{2} = 2.17 [5]. As in the case under consideration χ^2 = 0.85 < χ_{α}^{2} = 2.17 from a position of Pearson criterion it is possible to consider that beam distances follow the normal law, whose distribution density function *f (d)* has the following appearance:

$$f(d) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{(d-d_{cp})}{2\sigma^2}} , \qquad (2)$$

Slightly different picture is observed in case of beam distances on a port side which distribution for the same conditions is shown in Figure 3. Descriptive statistics of this sample is as follows: mean - 1.74; median - 1.3; fashion - 1.3; standard deviation - 0.74; dispersion - 0.626; excess kurtosis - 0.48; asymmetry - 0.82; reliability level (95.0%) - 0.15. Apparently, this distribution has much higher asymmetry (0.82

against 0.14 for beam distances from a starboard side). This distribution does not match to any parent distribution, however it can be presented

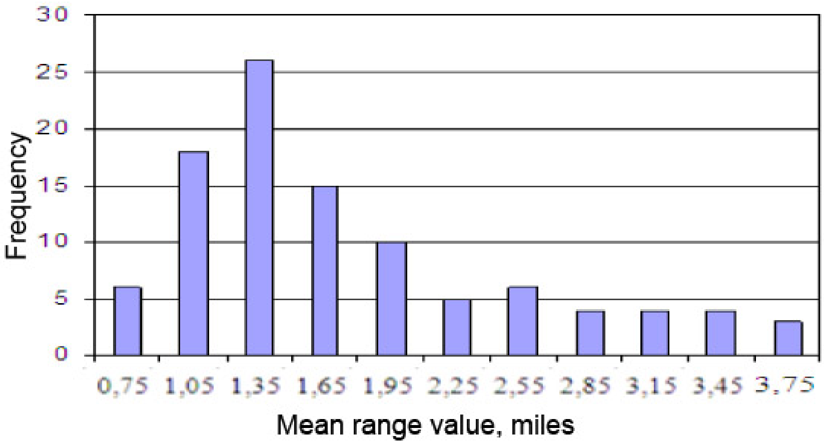

Figure 3. Distribution histogram of beam distances on a port side near the western entry to the Strait of Malacca

quite exactly (with reliability of 94.5%) by polynomial of degree 4.

It is interesting to note that distribution of beam distances, especially on a port side practically coincides with a density distribution of closest points of approach which has been used for ship domain conceptual baseline in the works of Toyoda S., Fujii Y. and E. Goodwin [6, 7]. This condition, on the one hand, comes from the fact that at those headings of ambient vessels which were fixed on AIS, beam distances practically coincided with closest points of approach, and on the other hand, once again it acknowledges theoretical rules and field studies presented in papers of Fujii Y. and E. Goodwin.

The second fact which should be noted is that maximums of beam distance points are different and reach 1.95 miles on a port side and 1.35 miles – on a starboard side. This fact may be due to the application of IRPCS-72 rules according to which the sector on the starboard bow is more dangerous, than the one on the port bow. And again, this implicit fact validates the hypothesis of E. Goodwin about asymmetry of the form of navigational safety zone [7]. Similar results concerning distribution of beam distances on the port side and on the starboard side, correlation of maximums of point density of beam distances have been received for the Red Sea and approaches to the Kammon Strait.

As to expected dependence of beam distances on a length of surrounding vessels, the results of observations at western entry to the

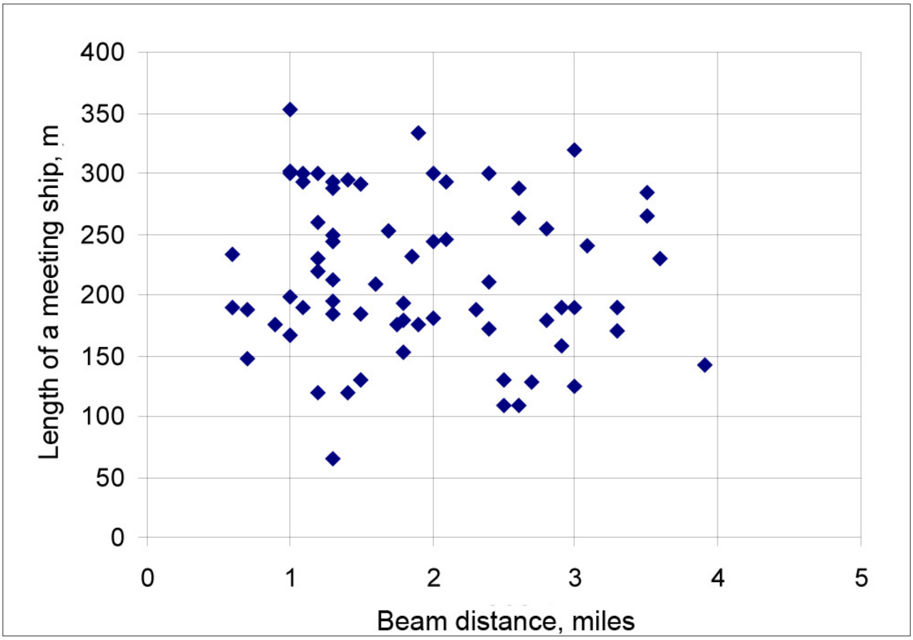

Figure 4. Dependence of beam distance on the length of a meeting ship

Strait of Malacca, presented in Figure 4, suppose the likely absence of such dependence.

The results presented in this work give additional information about traffic flow statistics and can be used in theoretical and experimental research linked, for example, with traffic flow modeling while studying various traffic routing plans.

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