Ship’s manoeuvring duration as a criterion of navigation safety within VTS areas

J. Guziewicz
Szczecin Maritime University, 70-500 Szczecin, Waly Chrobrego 1, Poland

Abstract

The paper presents simulation research to determine ship’s manoeuvring duration within restricted water areas. Ship’s manoeuvring duration has important influence for decision-makers (operators) of Vessel Traffic Services (VTS). The data of simulation research of ship approaching to berth in port of Police have been used to carried on presented investigation. Paper presents also manoeuvring duration analysis due to different factors influence.

1 Introduction

Growing traffic intensity on water areas influences for decreasing of navigation safety level. This phenomenon is inevitable and observed during last years. It is particularly visible within restricted water areas as port approaches, fairways, and port basins. One of methods to improve this situation is co-ordination and ships’ traffic management within these areas. The permanent-growing tendency of VTS (Vessel Traffic Service) systems development can be observed. These systems cover larger and larger water areas. The main goal of VTS system is to ensure safety of navigation and environment within own area of operation. Characteristic feature of such systems is access to wide range of information which make possible efficient ships’ traffic management. It means that density of ships’ traffic flow may be increased with simultaneous maintenance of constant safety level. But very important condition is credibility and accuracy of
information. One of methods to obtain such information is computer simulation method. Possibility of modelling many phenomenon accompanying ship’s movement and research influence many changing factors determines basic advantage of this method. The use of computer simulation model of ship movement for determine of manoeuvre duration of ship turning within turning area located on the fairway will be presented in this paper. The main thesis of paper is assertion if hydro and meteorological conditions have influence on ship turning duration. Results obtained in this investigation should present important information for VTS systems operators.

2 Navigation safety within VTS areas

The main aim of navigation process is to ensure ships traffic according with accepted parameters of this process. The basic parameter is safety. Navigation safety is strictly defined state of technical, organisational, operational and exploitation conditions. Rules, procedures and recommendations assisting navigation are also connected with navigation safety. Restricted water areas are the most of all subject to decreasing safety level due to ships traffic concentration. In such areas VTS systems are developed as aid to navigation. Main goals of systems concentrate on provision of service to assist improve safety and performance of navigation and environment protection. Main functions of system are:

- organising of traffic within restricted water areas,
- traffic supervising and controlling,
- navigation assist,
- rescue operation co-ordination,
- controlling of radionavigation systems functionality.

Ports equipped with these systems significantly improved navigation safety level. So that VTS systems could fully realised their functions it is necessary to build appropriate models of phenomenon connected with ships’ movement. The bases of modelling are empirical data obtaining as results of full scale or model research. It is arduous process but giving rational benefits. Simple example of such behaviour is presented in this paper use of computer simulation research to determine ship manoeuvre duration during turning. To carry on investigation, results of research done by Institute of Marine Traffic Engineering of Maritime University of Szczecin have been used.

3 Manoeuvre duration as a criterion of navigation safety

Navigation safety is dependent variable, conditioned by independent variables, which consist of many factors describing system: ship-water area - hydro and meteorological conditions. Direct determination of navigation safety is impossible due to large number of factors. In connection with this situation estimation of safety level is based on criteria. Criteria are numerical indicators
of navigation safety enable analysis of selected problems. Basic research problems connected with navigation safety within restricted water areas can be divided into two groups [3,6]:

- research problems of ship and water area interaction,
- research problems of ships traffic flow.

In second group of problems also problems of interaction between subsystem of ships traffic control and ships traffic flow can be distinguish. Ships traffic flow structure is very complicated and it is only one of numerous factors decided about parameters of traffic flow. Ships proceeding within traffic flow are keeping some guidelines of traffic, dependent on ensure necessity of safety level. If turning area is located on fairway then ship turning will force changes of ships traffic flow parameters. Main significance has manoeuvre duration, which will decide about time of fairway occupation. In case of unexpected change of manoeuvre duration the dangerous situation can appear, manifested excessive close up of ships in traffic flow. Then higher concentration of ships on fairway can be observed. It can be stated that ship manoeuvre duration within turning area located on fairway is safety criterion deciding also about capacity of fairway [1,2,3].

### 4 Simulation research of ship approaching Police port

An example of use of computer simulation method was research investigation entitled „Evaluation of navigational location of phosphoric acid terminal quay in port Police” [4,5]. This investigation was part of complex research entitled “Investigation of optimum location possibilities for phosphoric acid terminal quay in port of Police” done in Szczecin Maritime University.

The aims of research were following:

1. analysis of import possibility of phosphoric acid by sea to port Police,
2. choice of safe quay location from navigational point of view and optimisation her parameters,
3. idea of quay structures,
4. analysis of land based way forwarding acid construction.

Port of Police is situated about 30 km north of Szczecin near at Swinoujscie-Szczecin fairway (fig. 1). This port is a very important transportation centre for chemical factory "Police" joint venture. It was barge port at the beginning. Later due to increase of production in chemical factory also exportation grew up. Also assortment of products have been widened, which have extorted changes of transportation techniques. All together have contributed to necessity of considerable port modernisation. Planned port infrastructure within this area consist of:

- bulk cargo terminal in port of police,
- ferry passage between police and swieta,
- phosphoric acid terminal in port of police,
- ammonia and sulphuric acid terminal.
Figure 1. Location of Police port and all elements of waterway system infrastructures within this area

The computer simulation method has been used to realization second and third of point. The computer simulation model of ship movement on investigated water area includes model of ship movement and model of water area. Model of ship movement is based on analytic-experimental mathematical model of ship movement, where forces and moments acting on ship are calculated in function of which temporary speeds and accelerations of longitudinal, transverse and rotational movement are determined.
Computer simulation model has been prepared to work on computer of PC class. Investigations relied on execution of series of trials relying on passage from Swinoujscie-Szczecin fairway to turning area of Police and after turn entering with stern in Policki Nurt and berthing to projected quay of phosphoric acid terminal with starboard side alongside. All trials have been recorded on a hard drive with time interval of 2 seconds. Comparison of executed variants has been done by means of shipping safety criteria. Investigations has been done at following assumptions:

- computer simulation model is an interactive type,
- computer simulation model is real time type,
- captains and pilots participate in research,
- ship handling is done by officer in charge on a base of captain or pilot orders,
- presentation is "bird eye view" type,
- trials begun on fairway before 3 lengths of ship before turning area,
- starting position is random so that did not effect on final results.

Taking into account investor assumptions and quay exploitation accepted tanker of 16,400 DWT, which according with port regulations can enter and proceed through Swinoujscie-Szczecin fairway. This is biggest ship, which completely loaded can proceed through fairway called „Szczecinmax”. Ship’s parameters are following: length overall - 151, 5 m, breadth - 22, 4 m, draught - 9, 15 m.

Investigations variants have based on following assumptions:

- investigations should take into account winds directions, which are most inconvenient for ship manoeuvring possibilities,
- maximum speed of current is 0, 7 m/s,
- „Szczecinmax” ship should be used to investigations,
- manoeuvring ship is assisted by three tugs (according to port regulations),
- two ships are moored at existing berth in port of Police,
- contact moment of ship’s hull with fender is recognised as the end of trial.

Investigations have carried on three variants dependent on wind direction (N, SW and SE). Wind speed was accepted of equal 10 m/s. Number of trials were following: 18 in series with SE wind (sample marked as POL_SE), 16 in series with N wind (sample marked as POL_N) and 18 in series with SW wind (sample marked as POL_SW). On base of recorded trials determined ship manoeuvre duration. The area of turning has been assign as presented on fig. 2. Manoeuvre duration (ship within turning area) for series of trials is presented by histograms (fig. 3). It can be stated that variable in all samples has asymmetric distribution. It is confirmed by basic statistics as skewness and kurtosis (tab. 1).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mean</th>
<th>Std deviation</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>POL_N</td>
<td>673,5000</td>
<td>116,2767</td>
<td>1,704782</td>
<td>4,375472</td>
</tr>
<tr>
<td>POL_SE</td>
<td>683,5000</td>
<td>130,0870</td>
<td>1,715143</td>
<td>4,278106</td>
</tr>
<tr>
<td>POL_SW</td>
<td>768,1111</td>
<td>179,9251</td>
<td>0,683979</td>
<td>-0,029752</td>
</tr>
</tbody>
</table>
It indicates that normal distribution isn’t optimal mathematical model representing manoeuvring duration within turning area. Comparison of theoretical normal distribution and empirical distribution has been done to confirm above thesis (fig. 4). On presented graphs existing differences between straight line (theoretical normal distribution) and values of variable can be observed. Above mentioned thesis is also confirmed by Shapiro-Wilk test, which only don’t reject null hypothesis for sample POL_SW but with small probability level (tab. 2). Value of $p$ (probability value) represents probability that characteristics observed within sample represent general population.

Tab. 2. Results of Shapiro-Wilk test

<table>
<thead>
<tr>
<th>Sample</th>
<th>No of trials</th>
<th>W (value of statistics)</th>
<th>$p$ (probability value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POL_N</td>
<td>16</td>
<td>0.867275</td>
<td>0.024712</td>
</tr>
<tr>
<td>POL_SE</td>
<td>18</td>
<td>0.862384</td>
<td>0.013360</td>
</tr>
<tr>
<td>POL_SW</td>
<td>18</td>
<td>0.940419</td>
<td>0.294600</td>
</tr>
</tbody>
</table>

In order to precise determination of manoeuvre time determination of appropriate statistical is necessary. Statistica software has been used to reach this goal. Results of investigation was fitting following distributions (tab. 3):
- Extremly values distribution (Gumbel, type I) – sample POL_N i POL_SE,
- Lognormal distribution – sample POL_SW.

Test results were presented as different distributions ordered by best fit. Basic criterion was value of d-statistics (Kolmogorov-Smirnov test statistics). Difference of d-statistics for different distributions was not so high what means that such investigations should be continued to clearly indicate appropriate statistical model.
Figure 3. Histograms of ship manoeuvre duration for different conditions
Tab. 3. The best fitted theoretical to empirical distributions.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Distribution</th>
<th>Location parameter</th>
<th>Scale parameter</th>
<th>d Kolmogorov-Smirnov</th>
</tr>
</thead>
<tbody>
<tr>
<td>POL_N</td>
<td>Extreme values</td>
<td>625,5976</td>
<td>79,7246</td>
<td>0,074933</td>
</tr>
<tr>
<td>POL_SE</td>
<td>Extreme values</td>
<td>629,9579</td>
<td>88,7381</td>
<td>0,121874</td>
</tr>
<tr>
<td>POL_SW</td>
<td>lognormal</td>
<td>6,619</td>
<td>0,2283</td>
<td>0,108793</td>
</tr>
</tbody>
</table>

The extreme value distribution (Gumbel, Type I) has the probability density function:

\[ f(x) = \frac{1}{b} \cdot e^{-\frac{x-\Theta}{b}} \cdot e^{-e^{-\frac{x-\Theta}{b}}} \quad -\infty < x < \infty \]

where:
- \( \Theta \) - location parameter
- \( b \) - scale parameter

This distribution is also sometimes referred to as the distribution of the largest extreme and is often used to model extreme events.

The lognormal distribution has the probability density function:

\[ f(x) = \frac{1}{x \cdot \sigma \sqrt{2\pi}} \cdot e^{-\frac{\left(\log(x) - m\right)^2}{2\sigma^2}} \]

where:
- \( m \) - location parameter
- \( \sigma \) - scale parameter

Attention must be paid that assumed distributions are not to represent whole population due to low number of trials and samples. Unambiguous assumption of statistical models for investigated random variables requires long-lasting and wide scale research. Anyway for this specific reason ship manoeuvre duration can be estimated on a base of above mentioned distributions (tab. 4).

Tab. 4. Values of ship manoeuvring duration on different probability level [s].

<table>
<thead>
<tr>
<th>Sample</th>
<th>Distribution</th>
<th>P=95%</th>
<th>P=99,7%</th>
</tr>
</thead>
<tbody>
<tr>
<td>POL_N</td>
<td>Gumbel</td>
<td>862</td>
<td>1089</td>
</tr>
<tr>
<td>POL_SE</td>
<td>Gumbel</td>
<td>894</td>
<td>1145</td>
</tr>
<tr>
<td>POL_SW</td>
<td>Lognormal</td>
<td>1091</td>
<td>1403</td>
</tr>
</tbody>
</table>
Figure 4. Comparison of ship’s manoeuvring duration within turning area with normal distribution.
5 Summary

To summarised statistical analysis presented in this paper in a short form it can be ascertained, that:

- There are significant reasons to reject normal distribution as mathematical model of random variable, which is used to determine ship’s manoeuvring duration within turning area.
- Wind direction has influence on manoeuvring duration. Longest manoeuvre duration has been observed for SW winds, and shortest for N winds. With probability level equal 99.7% difference between manoeuvre duration is about 5 minutes.
- Presented investigation should be treated as indication of method, which let to optimal research of ship movement on restricted water areas from manoeuvre’s duration point of view.
- Obtained research results indicate necessity of research heading towards determination of investigated variable’s mathematical model, which let to appropriate modelling of VTS systems decisions algorithms.

References: