Combination of processing methods for various simulation data sets

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ABSTRACT: Computer based simulations can be used for assessment of traffic lane perimeters, and an actual level of risk at given area and given conditions. Navigational risk is defined as the product of probability of failure occurrence and the consequences it can cause. Additionally, the definition of risk was supplemented by relative frequency of performing the maneuver in given conditions and in given time *t*. In article method of simulation data possessing for maneuvers of approaching and entering to port, on base of specific vessels, is presented. Autonomous and non autonomous simulation methods are used for obtaining data sets, are supported in presented software solution, as well as restrictions in its implementation.

1 INTRODUCTION

Article presents complex method of possessing data from autonomous and non autonomous simulation. Such method is important in cases where complete navigation risk assessment must be fulfilled. This situation has place during new terminal development, on which non standard vessel will be handled.

2 AUTONOMOUS SIMULATION METHODS AT OPEN AREA

Autonomous simulations are valuable source of data where random phenomena's such as vessels collisions occurs. Autonomous simulations were determined with use of traffic analysis from past years for given area. In the next step probabilities of vessel collisions were obtained during simulation.

2.1 *Simulations of traffic stream at analyzed area*

For use of autonomous model, traffic densities at area must be gathered. Statistical data could be obtained from Automatic Identification System (AIS). AIS system is obligatory for any large vessel, but also smaller vessels do have AIS receiver. Land based monitoring stations, which works in area, can poses data from vessels such as:

- position,
- speed,
- course over ground,
- port of destination,
- port of departure,
- current status (for example: moored, under way etc.)

AIS gather data continuously, and its range allows tracking particularly any vessel in area covered by AIS. One day exemplary data from AIS are presented at Fig. 1.

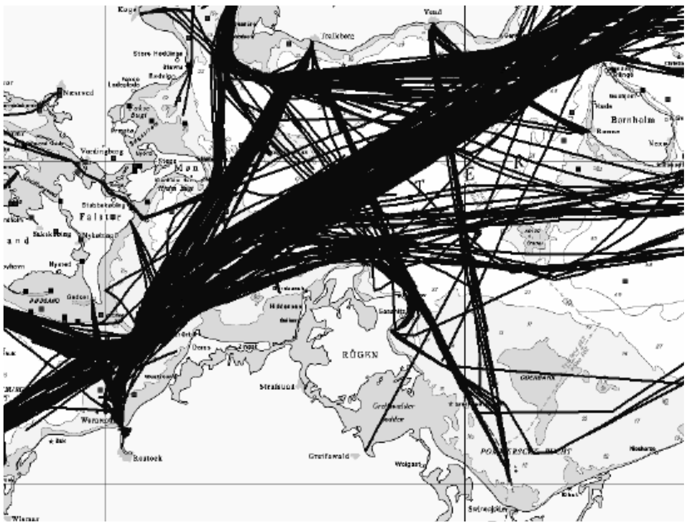

Fig. 1. One day AIS routes of ships

Data from AIS must be transformed into statistical streams of perimeters:

- number of vessels following same route,
- width of route,
- route legs,
- speed and structure of ships at route (transit or direct);

Such prepared data can be used to build model of traffic. Sample AIS streams situation is presented at Fig. 2.

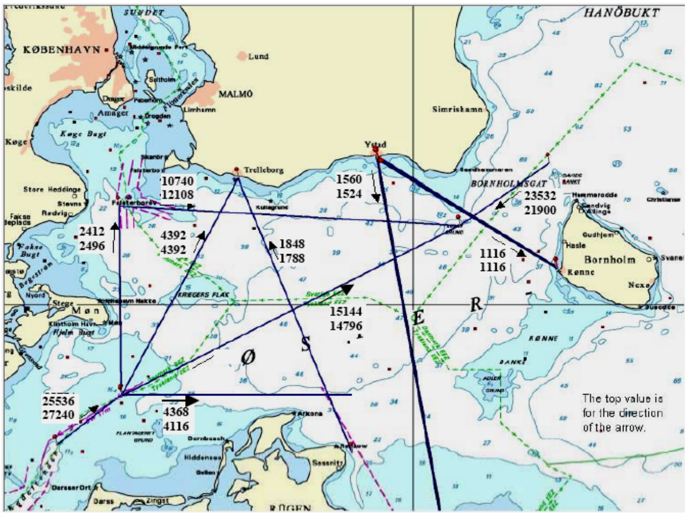

Fig. 2. AIS originated traffic streams

Total traffic stream at given route in discrete time lag (0, T) is presented as a random vector:

$$\dot{V}_c = \left(\dot{V}_{c,1}, \ldots, \dot{V}_{c,i}, \ldots, \dot{V}_{c,m}\right) \quad (1)$$

Any *i-th* element characterizes mean traffic stream between t_{i-1} and t_i and is a random variable with normal distribution $N(m_i, \sigma_i^2)$. Thus summary traffic stream can be expressed by generation of random variable with normal distribution $N(m_i, \sigma_i^2)$ that describes mean traffic stream $V_{c,i}$ in given lag time, which probability density function can be expressed by:

$$f(\dot{v}_{c,i}) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{\left(\dot{v}_{c,i} - m_i\right)^2}{2\sigma_i^2}\right) \quad (2)$$

Algorithm of traffic generation can be described by following points:

1. estimation of expected value m_i, and variance σ_i^2 for each model of traffic;
2. generation of random variables $x_1, \ldots x_m$ so that each value x_i came from set described by normal distribution as in point 1 of algorithm , i-$1, \ldots, m$;
3. estimation of expected value x_i as simulated stream in given time lag (t_{i-1}, t_i) for $i=1,\ldots,m$.

Generation of random variables was based on such realization of $\bar{X}$ for random variable X of distribution $S_\alpha(\sigma,\beta,\mu)$, with variable parameters $\alpha\in(0,2]$, $\beta\in(-1,1)$, $\mu\in\boldsymbol{R}$, $\sigma\in\boldsymbol{R}_+$ and can be developed by performing numerical equations:

$$\tilde{\mu} = \begin{cases} \mu - \beta\sigma^\alpha tg\left(\alpha\pi/2\right), & \alpha \neq 1, \\ \mu, & \alpha = 1; \end{cases} \quad (3)$$

$$\bar{V} = -\pi/2 + \pi\left(0.5 + k_1\right)/32767;$$

$$\bar{W} = -\log\left(\left(0.5 + k_1\right)/32767\right);$$

where constant: 32767 was obtained numerically and k_1, k_2, values are random [Izydorczyk A., Janicki A., 2001].

$$B_{\alpha,\beta,\sigma,\mu} = \tilde{\mu} - \beta\sigma^\alpha tg\left(\pi\alpha/2\right);$$

$$C_{\alpha,\beta} = \frac{arctg\left(\beta tg\left(\pi\alpha/2\right)\right)}{\alpha}$$

$$D_{\alpha,\beta,\sigma} = \sigma\left(\cos\left(arctg\left(\beta tg\left(\pi\alpha/2\right)\right)\right)\right)^{-1/\alpha},$$

thus for, $\alpha \neq 1$ function equals:

$$\bar{X} = D_{\alpha,\beta,\sigma}\frac{\sin\left(\alpha\left(\bar{V} + C_{\alpha\beta}\right)\right)}{\left(\cos\left(\bar{V}\right)\right)^{1/\alpha}}\left(\frac{\cos\left(\bar{V} - \alpha\left(\bar{V} + C_{\alpha\beta}\right)\right)}{\bar{W}}\right)^{(1-\alpha)/\alpha} + B_{\alpha,\beta,\sigma,\mu}, \quad (4)$$

and when, $\alpha = 1$ function equals:

$$\bar{X} = \sigma\frac{\pi}{2}\left(\left(\frac{\pi}{2} + \beta\bar{V}\right)tg\left(\bar{V}\right) - \beta\log\left(\frac{\frac{\pi}{2}\bar{W}\cos\left(\bar{V}\right)}{\frac{\pi}{2} + \beta\bar{V}}\right)\right) + B_{\beta,\sigma,\mu}, \quad (5)$$

with substituting:

$$B_{\beta,\sigma,\mu} = \mu + \frac{2}{\pi}\beta\sigma\log\left(\sigma\right).$$

Defined equations 4 and 5 are directly applicable in Monte Carlo model [Izydorczyk A., Janicki A., 2001]. Such defined model must be verified before usage and this process requires implemented computer structures.

Course and position variance of a vessel at given route is mainly contributed by changes in planning and keeping control over route by navigator and changes in keeping vessel at course due to hydro - meteorological conditions [Gucma L. 2005].

2.2 *Algorithm for assessment of vessels collision probability*

Probabilistic methods of analysis and estimation of risk was used to develop algorithm of collision assessment. Fault tree and collision assessment tree was applied.

Fault tree consist of analysis consequences during accident. This allows for building model inside which several factors were implemented. Some of these factors can be presented as: equipment fault, human factor (human error), environment influence and other. Reliability elements were applied as well, in order to build more detailed model, and its interactions between human and machine [Pietrzykowski Z. 2004].

Model of rendezvous for two vessels, which take into computation decision model of navigator, is presented at Fig. 5. One of major factor influencing work of this model is human behavior indetermination. One of possible decision making model of human behavior model is presented at Fig. 3 and Fig. 4.

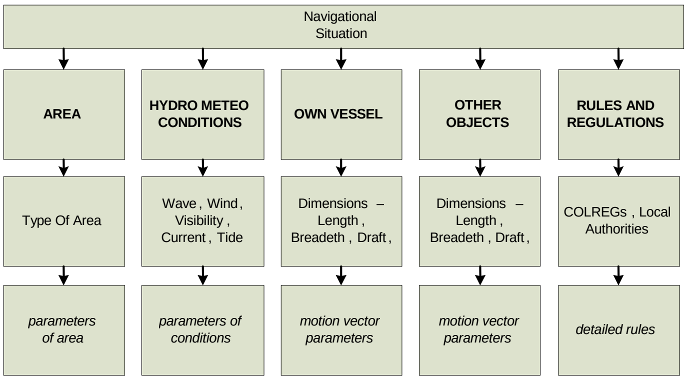

Fig. 3. Rendezvous model of two vessels [Pietrzykowski Z. 2004]

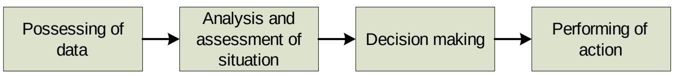

Fig. 4. Decision making process in human behavior model [Pietrzykowski Z. 2004]

Using such defined model, description and implementation of detailed fault tree for normal and failure states is possible. Then basing on literature and gathered experimental data, density distributions were determined. Such defined algorithm was tested using statistical data of accidents from past years at analyzed area.

3 AUTONOMOUS METHODS OF SIMULATION ON APPROACHES TO PORTS

On approaches to ports, from anchorages to entrance heads of particular ports, mainly straight line traffic occurs – changes of courses are not significant. Maneuvering on such area is quite simply and do not need to apply direct control by human navigator. Thus fast time autonomous simulation could be used in order to assess probability of grounding at such area.

Main advantages of fast time autonomous simulations in comparison to non autonomous models are[Gucma S., 2001]:

– much shorter period of time used to perform simulations,
– lower costs of researches due to lack of hiring experts to perform its,
– possibility of testing model in different conditions.

In this type of simulations, modeling of decision making process on base of human behavior is crucial element. When maneuver must be done, decision making process is very flexible and its parameterization is difficult. Also individual preferences are very important when human navigates.

Predictive models are used in order to build fast time autonomous models. These systems are constructed using mathematical model of vessel movement. Simulation autonomous model with respect to dependence function vessel – area – navigator is presented at Fig. 5.

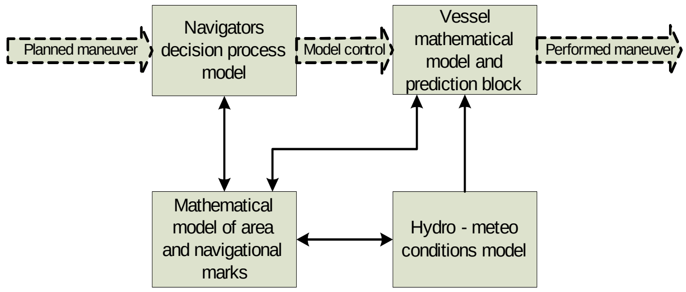

Fig. 5. Autonomous simulation model of movement vessel at restricted area [Gucma S. 2001]

4 NON AUTONOMOUS SIMULATIONS

During entering the port, turning and mooring operations maneuvering the vessel is extremely complex process, thus in order to estimate collision probability vessel with hydro constructions, real rime non autonomous simulations are deployed. Complete description of method can be found in large literature of MTE filed for example: [Gucma L. 2005], [Gucma M. 2006] and other.

Real time human – computer interaction is used for development of this type of simulators. Human is usually an expert that has proper experience in maneuvering at given area. Computer has specialized subsystems for visualization and controlling vessel mathematical model. Such model is presented at Fig. 6.

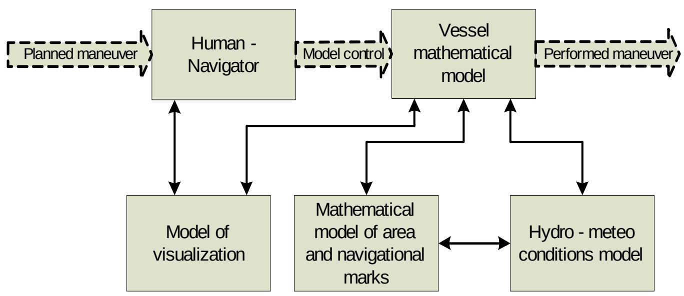

Fig. 6. Non autonomous simulation model of vessel movement at restricted areas [Gucma S. 2001]

This method is much more accurate than fast time autonomous simulations, but its application is more expensive and time consuming than the latter. Performance of these maneuvers can be done at 2D limited task simulator as well as 3D full mission simulator. Marine Traffic Engineering Institute has developed variety of limited task simulators for different navigational situations – example of these is presented at Fig. 7. Full mission simulators from third parties are used as well when reality is indispensable for researches – Fig. 8.

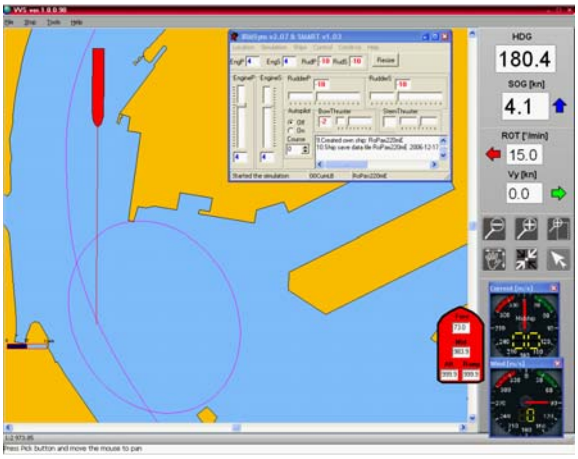

Fig. 7. Limited task simulator used for marine traffic engineering researches

Fig. 8. Real time full mission simulator used for marine traffic engineering researches

The vessel performing a given manoeuvre in an accessible navigational area occupies a certain area determined by her successive locations in the area. The parameters of this area are random and depend on various factors. This area, calculated on a definite reliability level is called safe manoeuvring area. A safe manoeuvring area so defined can be presented in the form of area $\mathbf{d}_{ijk}$ (set of points) and the basic navigational safety condition can be written down as follows [Gucma S. 2001]:

$$\left.\begin{array}{l} \mathbf{d}_{ijk} \subset \mathbf{D}(t) \\ {}_{p(x,y)\,\in\,\mathbf{D}(t)}\; h(,y,t) \geq T(x,y,t) + \Delta(x,y,t) \end{array}\right\} \quad (6)$$

where:

$\mathbf{D}(t)$ – accessible navigational area (meeting the condition of accessible depth at moment t),

$\mathbf{d}_{ijk}$ – accessible manoeuvring area (traffic lane) of the i-th vessel, performing the j-th manoeuvre in k-th navigational conditions,

$h(x, y, t)$ – the depth of the area at point with coordinates (x, y) at moment t,

$T(x, y, t)$ – the draft of the vessel at area point with coordinates (x, y) at moment t,

$\Delta(x, y, t)$ – underkeel clearance at area point with coordinates (x, y) at moment t.

5 RESULTS COMBINATION OF DIFFERENT METHODS

Important application of Monte Carlo models are the methods used for the determination of probability of damage of underwater pipelines by the ship after emergency dropped anchor [Gucma L. 2005]. Such models need long time of simulation because modelled events are very rare. The example algorithm of second category of MC based models is presented on Fig. 9.

The example result as distribution of anchor – pipe accidents are presented on Fig. 10. The interesting analysis can be made by the investigation of times between accidents (Fig. 11). Usually due to stochastic nature of simulated process, the distribution of times between accidents is exponential (Fig. 11).

Fig. 9. General procedure of MC researches based on generalized simulation data

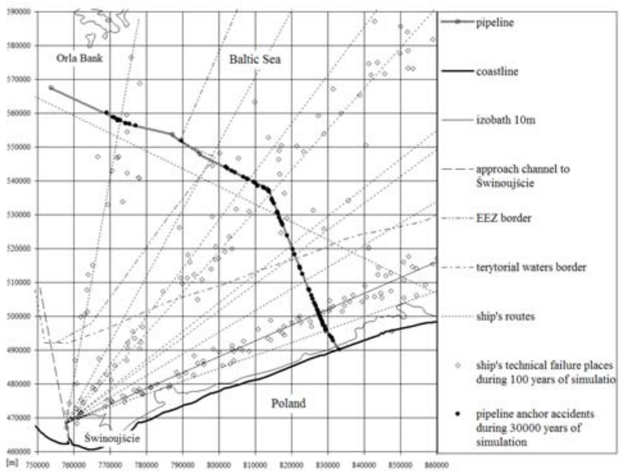

Fig. 10. Localizations of simulated anchor accidents during whole simulation time and examples of technical engine break out as the main causes of such accidents during 100 years of simulation [Baltic Master Report, 2006]

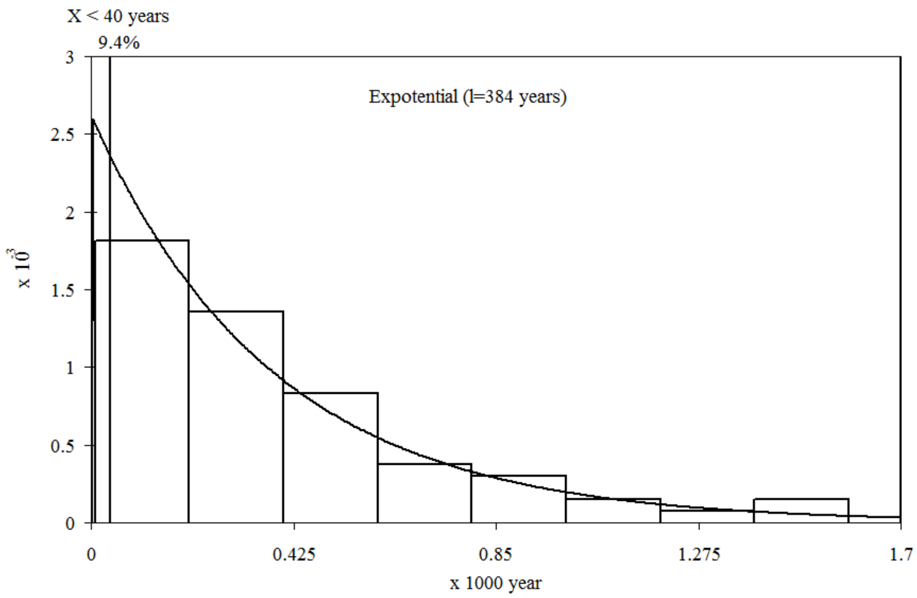

Fig. 11. Distribution of times between consecutive gas pipeline damages [Baltic Master Report, 2006]

Other result type consists of non autonomous simulations performed at confined port areas. The probabilistic concept of safety manoeuvring area obtained from these type of simulations. is presented on Fig. 12. The distributions are strongly dependant of waterway area arrangement and could be evaluated in simulations and validated in real experimentations.

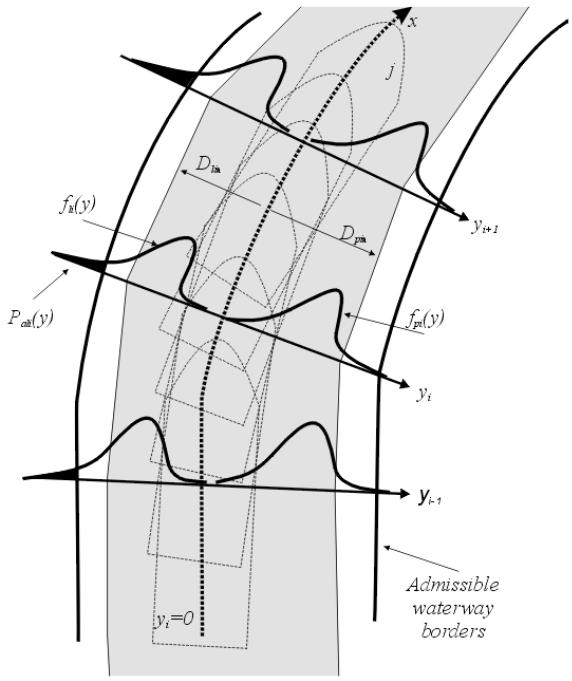

Fig. 12. Probabilistic concept of safe maneuvering area determination on the waterway [Baltic Master Report, 2006]

6 CONCLUSIONS

Both non autonomous simulations and autonomous ones, requires thoroughly processing and deep knowledge of process itself, for correct analysis.

Presented combination of marine traffic engineering tools allows to develop complete method of risk assessment at particularly any area. Method has been recently used for LNG carrier maneuvering at Southern Baltic and prospected terminal at Polish coast at work: [Gucma S., Gucma M., 2007].

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