Calculation of parameters for altering the ship’s course at sea using Artificial Neural Network (ANN)

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Abstract. During ship manoeuvring and course alteration, the trajectory of ship or the time of ship’s turning which remarkably affect safety and effectiveness of navigation depends on ship’s factor, meteorological factor and control factor. Simulation commonly is applied for methods used for calculating the ship’s trajectory. However, these computed results which are only applied for simulated cases or for certain external affected conditions are not reliable enough for navigation officers to predict the ship’s turning index in practical situations. In this article, authors propose the model for calculating the ship’s course alteration by applying artificial neural network in order to assist navigation officers making decision of manoeuvring ship safely and effectively, especially in emergency situations.

1. Introduction
The operation of the maritime route is intended to be a basic operation of the marine officer, which is the basis for the captain to plan a safe and economical sea voyage. The theoretical basis and common practice guidelines are documented in the International Maritime Organization (IMO) documents [1, 2] and the company’s processes in the International Safety Management System (ISM) [3-5]. However, these are just the most basic and general guidelines, in order to establish a maritime route that envisages quality it requires many specific maritime operations. In this paper, the author specifically discusses two basic issues that need to be calculated when planning a maritime route, piloting it in Vietnam's coastal areas.

The first is the Margin of safety (MOS): when operating a specific route, maritime officers need to determine the safe distance to dangerous areas. However, the theoretical and practical basis for giving the specific value of MOS has not been guided in research papers as well as practical experience.

The second is the frequency of determining the position of the ship (Interval Fixed Positions - IFP): Locating the ship is a necessary and mandatory job for the duty watch officer at sea. The purpose of maintaining the time interval between ship location determinations is to have a basis for adjusting the intended position, leading the ship on the correct course. However, the theoretical and practical basis for the captain to decide the time to locate the ship as well as the full awareness of the duty officer on this issue has not yet had adequate instructions on the ship.
2. Ship turning problem

2.1. Ship’s turning

When a Ship alters her course under helm through 360 degrees she moves on a roughly circular path called a turning circle [6, 7]. Throughout the turn her bow will be slightly inside the circle and her stern a little outside it. The circle will be the path traced out by her centre of gravity.

Circulation is characterized by linear and angular speeds, radius of curvature and a corner of drift. These characteristics do not remain constants during movement on a curvilinear trajectory (figure 1).

- The first period – maneuverable - proceed during time from submission of a command on rudder before it’s moving on the set corner.
- The second period – evolutionary - begins from the moment of the ending process set a rudder and comes to an end, when characteristics of circulation will accept the established values.
- The third period – established - begins from the moment of the ending of the second period and proceeds until the rudder remains in the shifted position.

2.2. Ship’s turning

Parameters of ship turning circle (figure 2).

![Figure 1. Trajectory of ship.](image1.png)

![Figure 2. Parameters of ship turning circle.](image2.png)
Tactical diameter: The value of the transfer when the ship's heading has changed by 180 degrees. It should be noted that the tactical diameter is not the maximum value of the transfer (figure 3).

Diameter of steady turning circle: Following initial application of the rudder there is a period of transient motion, but finally the speed, drift angle and turning diameter reach steady values. This usually occurs after about 90 degrees change of heading but, in some cases, the steady state may not be achieved until after 180 degrees change of heading. The steady turning diameter is usually less than the tactical diameter.

Pivoting point: This point is defined as the foot of the perpendicular from the centre of the turn on to the middle line of the ship extended if necessary. This is not a fixed point, but one of which varies with rudder angle and speed. The turning circle has been a standard maneuvering carried out by all ships as an indication of the efficiency of the rudder. Apart from what might be termed the 'geometric parameters' of the turning circle defined above loss of speed on turn and angle of heel experienced are also studied.

Advance: The distance traveled by the centre of gravity in a direction parallel to the original course after the instant the rudder is put over. There is a value of advance for any point on the circle, but if a figure is quoted for advance with no other qualification the value corresponding to a 90 degree change of heading is usually intended.

Transfer: The distance traveled by the centre of gravity perpendicular to the original course. The transfer of the ship can be given for any point on the circle, but if a figure is quoted for transfer with no other qualification the value corresponding to a 90 degree change of heading is usually intended.

Drift angle: The drift angle at any point along the length of the ship is defined as the angle between the centre line of the ship and the tangent to the path of the point concerned. When a drift angle is given for the ship without any specific point being defined, the drift angle at the centre of gravity of the ship is usually intended.

Loss of speed on turn: As discussed above, the rudder holds the hull at an angle of attack, i.e. the drift angle, in order to develop the 'lift' necessary to cause the ship to accelerate towards the centre of the turn. As with any other real lined form, hull lift can be produced only at the expense of increased drag. Unless the engine settings are changed, therefore, the ship will decelerate...
under the action of this increased drag. Most ships reach a new steady speed by the time the heading has changed 90 degrees but, in some cases, the slowing down process continues until about 180 degrees change of heading.

- Angle of heel when turning: When turning steadily, the forces acting on the Ship is $F_r$ (figure 4) [8].

![Figure 4. Force producing heel when turning.](image)

where:

$$F_r = \frac{m \times V^2}{r}$$

we have:

$$M_n = D \times h \times \sin \theta = \frac{m \times g \times V^2}{g \times r} \left( Z_G - \frac{d}{2} \right) \cos \theta$$

$$tg \theta = \frac{m \times g \times V^2}{D \times h \times r \times g} \left( Z_G - \frac{d}{2} \right)$$

$$\theta_{\text{max}}^0 = 1.4 \frac{V^2}{h \times L} \left( Z_G - \frac{d}{2} \right)$$

or:

$$\theta_{\text{max}}^0 = 1.54 \frac{V^2 \times b}{r \times h}$$

where:
- $m$: Mass of Ship
- $D$: Displacement
- $g$: Acceleration of gravity (9.81 m/s²).
- $V$: Speed of Ship (m/s).
- $F_r$: Radial force
- $\theta$: Angle of heel
- $r$: Turning Radius
- $h$: Height
• d: water-line
• ZG: Height of Centre of gravity.
• b: Distance of Centre of gravity (G) and Centre of buoyancy (B) of Ship

Effect of the wind and current on ship turning

A Ship stemming the stream at slow speed may complete the first part of her turning circle almost within her own length, as the stream runs against the Ship broadside. A Ship running downstream may well develop double the speed over the ground normally attained in slack Water by the existing engine revolution and if the is turned the radius of the first 90 degrees of turn is far in excess of her rudder water swing [9-11]. The deep of current effect on Diameter of turning circle follow figure 5:

![Figure 5. Effect of the current on Ship.](image)

3. Problem solving

The alteration of course without any divergence from intended track is very important, especially computerization the Ship’s characteristics, maneuvering characteristics, meteorological and hydrographic conditions...when turning. In this paper, we propose a method with applied Neural network technique and its learning processes in computing influences of environment factors when turning with purpose to raise the level of ship maneuvering safety.

3.1. Neural network

The Artificial neural was designed to mimic some of characteristic of the biological neuron. Each neuron has a set of inputs are one or more outputs. A weight is analogous to the synaptic strength of a biological neuron. All the inputs are multiplied by their weight and then are summed to determine the activation level of the neuron. Once the activation level is determined, an activation function is applied to produce the output signal. Figure 6 presents an artificial neuron that has n inputs, labels x1, x2,...xn, and once output denoted by y [5, 6].

![Figure 6. Architecture of an artificial neural.](image)

The output y can be produced as:

\[ y = f(u) \]
where:

\[ u = \sum_{i=1}^{n} x_i w_i \]

and \( f \) is an activation function.

3.2. Neural network for Ship’s turning problem

Based on parameters of the ship when turning, the theory of neural network, the neural network model selected: the Recurrent neural network with supervised learning algorithms.

The recurrent neural network with three layers: Input layer, Output layer and Hidden layer (figure 7) [7].

![Figure 7. ANN for ship’s turning problem.](image)

Where:

**Input data:** LoA, d, A_R, r, b, h, V, \( Z_g \), \( \delta \), \( \beta \)
- LoA: Length of Ship;
- d: water-line;
- A_R: Area of rudder;
- r: Turning Radius;
- b: Distance of Centre of gravity (G) and Centre of buoyancy (B) of Ship;
- h: Height of Ship;
- V: Speed of Ship (m/s);
- \( \delta \): Angle of attack;
- \( \beta \): Drift angle.

**Output data:** \( D_n \), \( \theta \), \( T_R \), \( A_d \), \( A_o \).
- \( D_n \): Diameter of turning circle;
- \( \theta \): Angle of heel;
- \( T_R \): Transfer;
- \( A_d \): Advance;
- \( A_o \): Advance of opposite.
3.3. Neural network training
By analysis ship’ maneuver simulation, ship’s characteristics, maneuvering characteristics, meteorological and hydrographic conditions, establishing mathematical model of ship’ turning, using Unsupervised learning algorithms of Neural network for solving problem give us high accurate result [8].

The network training processing following figure 8:

![Figure 8. Network training processing.](image)

The ship’ turning with parameters following figure 9.

![Figure 9. Ship’s turning simulation.](image)

3.4. Case study
The problem determines the Wheel Over point and Wheel Over angle of which Completed Turning Point – CTP locates on the new course [9].

Input:
- Ship Particulars
- Wheel Over Angle
- Wind
- Curent
- Dead Weight

Output:
- CTP on the new course (or plotted point)
- Minimum turning time
- Wheel Over Angle: 10° ± 20°

Test the program with MV. NAVIGATOR
Ship Particulars
- Ship Type: General Cargo
- DWT: 6500T
- Gross Tonnage: 4089
- Speed: 15.2 kts
- LOA: 102.79 m
- Breadth: 17 m
- Summer Draft: 6.95 m

Input
- Current Course HT1: 270°
- Next Course HT2: 323°75
- Position A/C: 20041'6N, 107059'5E
- Rate of the Current (HN): 2360
- Speed of the Current (VN): 2.0 kts
- Advance: 0.55NM
- Transfer: 0.12NM
- Rate of Angular Turning (ωT): 22 (Degree/Minute)
- Wheel Over Angle (θ): 20°

Output
- Position of WO (W): 200041'6N, 107057'85E
- Position of WO (O): 20015'0N, 108059'35E
- Correction (W → O): 0.15 NM

Maneuvering indexes are computed by ANN as shown in Table 1.

| Input   | Output          |
|---------|-----------------|
| HT1     | 270             |
| HT2     | 323°75          |
| ΦA      | 20°41'6         |
| λA      | 107°59'5        |
| ωT      | 22              |
| V_N     | 02              |
| Adv     | 0.55            |
| Tra     | 0.12            |
| θ       | 20              |
| λ_w     | 108°25'0        |
| ω_o     | 20°15'0         |
| λ_o     | 108°25'0        |
| W-O     | 0.22            |

Table 1. Computing the WO points of MV. NAVIGATOR.

Applying computed results to practical ship maneuvering in Lach Huyen fairway – Hai Phong, initial position (O) with bearing and distance to Fairway Buoy (HP0) 1580 - 0.4 NM, angle of course alteration - 200 starboard, at final position ship is steady on 3240, on the center line of fairway (figure 10).

Figure 10. Altering course of MV. NAVIGATOR in Lach Huyen fairway.
By applying a combination of verification method, correction method and neural training in many situations, it is realized that applying ANN in computing the ship turning index is possible and will assist navigation officers in maneuvering ship safely and effectively.

4. Conclusion
The alteration of course without any divergence from intended track is very important, especially computerization the ship’s characteristics, maneuvering characteristics, meteorological and hydrographic conditions...when turning. Base on theory Neural network, coordinate analysis ship’s characteristics, maneuvering characteristics, meteorological and hydrographic conditions we propose a model Neural network and its learning processes in computing influences of environment factors when turning with purpose to raise the accurate and level of ship maneuvering safety.

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