Risk and Emergency Management for a HVU (High Value Unit) Ship

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Abstract: - The authors propose the use of Modelling and Simulation (M&S) in order to study the detection probability of a HVU (High Value Unit) ship by a hostile submarine moving in a sea environment and taking into account all the parameters like speed, wind, sea conditions and so on.
The authors have developed a methodology devoted to identify the detection probability of the HVU unit, accompanied by a ship in a ASW (Anti Submarine Warfare) configuration, by the submarine, which tries to sink the unit, in two different conditions: one of "Barrier Patrol", in which the ASW unit moves in both radial and tangential directions, guaranteeing the isochronism, and one of "Sprint and Drift", in which the radial component does not exist and so the ASW unit has to recalculate his position to re-establish the distance from the HVU.
In the first part will be proposed the mathematical demonstration of the phenomenon, while in the second part a brief description of the model will be presented.

Key-Words: - Risk Management, Monte Carlo Simulation, Emergency Procedures,

1 Introduction

The reference scenario used for the tests shows a HVU (High Value Unit) Ship, that is a unit shipping high trade value goods, navigating at a fixed *v* speed; this HVU is moreover escorted by another unit in ASW (Anti Submarine Warfare) trim, then predisposed to manage hardware and software systems and for the anti-submarine war both in terms of attack and defence weapons. In the studied case, the unit ASW mode is double, since it has a research (Barrier Patrol) and Sprint & Drift function. The ASW in the considered scenario moves at a *w* speed.
Moreover in the scenario there is an antagonist submarine moving at a $u < v$ speed trying to force the surveillance action starting from a point inside the approach area.
The Test Case target is that to supply a Discovery Probability evaluation of this threat as well as of the same neutralisation.

2 The Scenario

Now we will consider some important data for the scenario: the hostile submarine has an attack range with respect of the HVU (said also *Danger Area Range*) equal to *R*, while the angle between the HVU *v* speed and the *u* submarine one, changed of sign, is defined as *q=arcsin (u/v),* moreover it is defined as *t* the maximal time within which the attack should be ended.
The HVU, in this temporal space, will cover a distance equal to *vt* (represented with the OG segment), for which the submarine shall be, to hit the commercial unit, at first at a distance shorter than *vt* from the Danger Area (the circle with the OR radius called A).
Considering the isochrone with G centre and the radius equal to $R + ut$ and the two half-lines r and s getting out from the L point, inclined leftward and rightward, respectively, of ˜*q*e . *q*, determinate the tangency points M and N, which will

become M' and N', in the case that at the beginning time t0 the submarine would be already inside the A area.
In the light of all that, the B area, from which a submarine successful attack could start, is only that included in the circumference arc between M and N, the MM' and NN' segments on the half-lines *r* and *s* and the M'N' circumference arc.

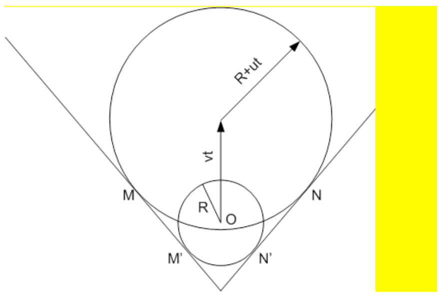

Fig. 1:Patrolling Kinematics

3 The Applied Methodology

In order to achieve an analytic expression of the precursory operation action efficiency we make reference to the treated considerations concerning the linear barrier patrol; keeping into consideration that they differ from the concerned case for three important points:

1) the screen position is fixed in geographic coordinates
2) the screen shape is rectilinear
3) the patrol and boat absolute speeds are perpendicular

In the case of the Linear barrier patrol, the probability that the screen discovers a boat is equal to:

$$p \cong \frac{PSR}{L}\sqrt{1+\frac{v^2}{u^2}}$$

where:

L: screen length
v: patrol absolute reference speed
u: boat absolute reference speed
PSR patrol sensor range performance

In order to adapt this configuration to the concerned case, it is necessary to distinguish two cases:

a) standard operation in which the Ship Unit carrying out the precursory sanitation moves continuously along the isochrones while it contemporarily advances with the group V HVU speed.
b) Sprint&Drift, in which the movement of the patrolling Ship Unit shows two different phases:
   1. Drift: that is the movement along the MKN arch not maintaining the equidistance from the HVU group.
   2. Sprint: an advancing movement at a higher speed compared to that of the HVU group so as to averagely maintain at each sprint&drift cycle the distance from the units which you want to protect.

The standard operation requires high ship performances above all in terms of acoustic self noise at the speed changing, indeed the patrolling Unit must move at a speed showing two significant components: the advancing speed of the ship group and that of patrolling to explore the screen arch.
In case of Sprint&Drift it allows to solve the problems mentioned above since the patrolling requires only a speed component along the arch to explore. This case shows the limit that during the Sprint phase the Ship Unit cannot use its sensors; it is for this reason that the Sprint&Drift operations are carried out by a Unit couple.

3.1 Standard Case

Given that:
- W the maximal patrolling Unit speed in which the PSR sensor performance is sure.
- V the HVU group advancing speed
The Linear Barrier Patrol analytic formulation can be transformed as shown in the following analytic passage:

$$p \cong \frac{PSR}{L}\sqrt{1+\frac{v_{unit}^{2}}{u_{sub}^{2}}} = \frac{PSR}{L}\sqrt{1+\frac{\vec{W}^2-\vec{V}^2}{\left(\vec{U}+\vec{V}\right)}} =$$

where the v_{unit} and u_{sub} speeds have been transformed keeping into consideration that in the concerned case the reference to consider for the movements is that centred on the HVU moving with the V speed
by executing the suitable vectorial operation we can obtain:

$$p = \frac{PSR}{\left(\vec{U}+\vec{V}\right)L}\sqrt{\vec{U}^2+2\vec{U}*\vec{V}+\vec{V}^2+\vec{W}^2-\vec{V}^2} =$$
$$= \frac{PSR}{\left(\vec{U}+\vec{V}\right)L}\sqrt{\vec{U}^2+\vec{W}^2+2\vec{U}\cdot\vec{V}} = \frac{PSR}{\left(\vec{U}+\vec{V}\right)L}\sqrt{U^2+W^2+2U\cdot V\cos\vartheta} =$$

the ϑ angle displayed above has not a fixed value but it varies with the Unit position changing and patrolling along the MKN isochrone; when the Unit is in the M and N position the $\vartheta = \theta$, in the K position, we have $\vartheta = 0$ and intermediate values between θ and 0 in the other positions.
These considerations suggest to transform the previous analytic formulation in the following one:

$$p = \frac{PSR}{\left(\vec{U}+\vec{V}\right)L}E(U,V,W)$$

where:

$$\widetilde{E}(U,V,W) = \frac{1}{N+1}\sum_{i=0}^{N}\sqrt{U^2+W^2+2U\cdot V\cos\left\{-\theta+\frac{2(\theta)}{N}i\right\}}$$

being $\widetilde{E}(U,V,W)$ a mediated average value keeping into consideration the different angulations between U and V along the different isochrone positions.
Case 1:Non Sprint&Drift:

3.2 Sprint & Drift Case

Given that:
- W_d the Unit speed in the drift phase along the MKN isochrone
- W_s the Unit speed in the sprint phase
- V the HVU group advancing speed

The Linear Barrier Patrol analytic formulation can be transformed as shown in the following analytic passage:

$$p \cong \frac{PSR}{L}\sqrt{1+\frac{v_{unit}^{2}}{u_{sub}^{2}}} = \frac{PSR}{L}\sqrt{1+\frac{\vec{W}_d^{2}}{\left(\vec{U}+\vec{V}\right)}} =$$

by executing the suitable vectorial operation we can obtain:

$$p = \frac{PSR}{\left(\vec{U}+\vec{V}\right)L}\sqrt{\vec{U}^2+2\vec{U}*\vec{V}+\vec{V}^2+\vec{W}_d^{2}} =$$
$$= \frac{PSR}{\left(\vec{U}+\vec{V}\right)L}\sqrt{\vec{U}^2+\vec{W}^2+2\vec{U}\cdot\vec{V}+\vec{V}^2} = \frac{PSR}{\left(\vec{U}+\vec{V}\right)L}\sqrt{U^2+W_d^{2}+2U\cdot V\cos\vartheta+\vec{V}^2} =$$

the ϑ angle above displayed has not a fixed value but it varies with the patrolling Unit position along the MKN isochrone.
These considerations suggest to transform the previous analytic formulation in the following one:

$$p = \frac{PSR}{\left(\vec{U}+\vec{V}\right)L}E(U,V,W_d)$$

where:

$$\widetilde{E}(U,V,W_d) = \frac{1}{N+1}\sum_{i=0}^{N}\sqrt{U^2+W_d^{2}+V^2+2U\cdot V\cos\left\{-\theta+\frac{2(\theta)}{N}i\right\}}$$

being $\widetilde{E}(U,V,W_d)$ a mediated average value keeping into consideration the different angulations between U and V along the different isochrone positions.

In order to calculate the T_d and T_s periods of the drift and sprint phases the following considerations are valid:

$$T_d = \frac{W_d}{L}$$ (drift time along the isochrone)

$$V*T_d + V*T_s = W_s*T_s$$

(positions relevant to the patrolling Unit and the HVU group which are unchanged at the end of a drift and sprint phase) from which:

$$Ts = \frac{V*T_d}{(W_s-V)} = \frac{W_d}{L}*\frac{V}{(W_s-V)}$$

4 A Practical Application: Development of a Monte Carlo Simulation Model for the non Sprint & Drift Scenario

The above displayed non sprint and drift scenario analysis makes possible to develop a simulation model able to reproduce the screen procedure and to experimentally verify what expressed in analytic way. In order to better describe the scenario and formulate the same inside the simulation model some consideration of cinematic character have been better explained.

The non sprint and drift scenario (scenario 1) provides the presence in the operation theatre of three different Ship Units, particularly we have the HVU unit moving with a rectilinear movement along the x axe with a constant v speed. The patrol unit providing the screen along the isochrone referred to the HVU ship, before in the time of a Δt quantity and equipped of sensors able to identify a submarine at a maximal distance equal to PSR, this ship unit moves along the isochrone with a w speed able to maintain it at a constant distance from HVU in any time (isochronicity condition). Finally the submarine moves with a u speed towards the HVU Unit towards the O' future point where, after having reached a minimal distance equal to R (Torpedo Danger Zone or TDZ) it shall began its attack action. According to this scenario, we have the following considerations and hypothesis:

1. ***Isochronicity condition*** In any time the patrol unit position shall be constant with respect to the HVU and the patrol unit shall have a constant length;
2. ***Angle congruence:*** the route along the isochrone imposes that the arch described by the patrol unit with respect to the HVU, is proportional to the product between the (λ) distance between the Ship Units and the angle subtended between the HVU prow and the patrol unit position
3. ***Threat plausibility:*** to make possible the submarine attack, its position shall be included within an MN circumference arch with a width equal to π + 2θ a R + uT radius and a vT centre where T shows the maximal time in which the submarine can achieve the attack manoeuvre.

The three previous condition analysis makes possible to obtain the parametric equations in the three Ship Unit movement absolute coordination particularly from the analysis of the 3 for the escort unit we obtain:

$$dS = \lambda \cdot d\theta \quad (1)$$

from which, showing with *l'* the patrol unit speed tangential to the isochrone, we obtain:

$$l' = \frac{dS}{dt} = \lambda \cdot \frac{d\theta}{dt} = \lambda \cdot \varpi \quad (2)$$

Having shown with ω the angular speed with which θ varies during the operation, this angle, indeed, will vary between -θ and +θ as they have been previously calculated, in each time it will then know the HVU position and that of its patrol unit according to the following simple trigonometric considerations. Considering an absolute reference solid with the HVU, the escort frigate position along X will be:

$$X_s(t) = \lambda \cdot \cos\theta(t) = \lambda \cdot \cos(\varpi t) \quad (3)$$

while along Y will be:

$$Y_s(t) = \lambda \cdot \sin\theta(t) = \lambda \cdot \sin(\varpi t) \quad (4)$$

In this way it will be possible to calculate the patrol unit speed with respect to the HVU respectively in:

$$\dot{X}_s(t) = -\lambda \cdot \varpi \cdot \cos(\varpi t) \quad (5)$$

and, obviously:

$$\dot{Y}_s(t) = \lambda \cdot \varpi \cdot \sin(\varpi t) \quad (6)$$

Passing then to an inertial reference, being the HVU equipped of a single v speed along the X axis, we obtain:

$$\dot{X}_s(t) = v - \lambda \cdot \varpi \cdot \cos(\varpi t) \quad (7)$$

$$\dot{Y}_s(t) = \lambda \cdot \varpi \cdot \sin(\varpi t) \quad (8)$$

By remembering the (1), it is possible to obtain the ϖ angular speed expression as:

$$\varpi = \frac{d\theta}{dt} = \frac{1}{\lambda} \cdot \frac{dS}{dt} = \frac{l'}{\lambda} \quad (9)$$

that replaced in (7) and (8) gives the parametric equations of the patrol unit movement:

$$\dot{X}_s(t) = v - \lambda \cdot \frac{l'}{\lambda} \cdot \cos\left(\frac{l'}{\lambda}t\right) = v - l' \cdot \cos\left(\frac{l'}{\lambda}t\right)$$

(10)

$$\dot{Y}_s(t) = \lambda \cdot \frac{l'}{\lambda} \cdot \sin\left(\frac{l'}{\lambda}t\right) = l' \cdot \sin\left(\frac{l'}{\lambda}t\right)$$

(11)

From which it is easy to calculate the escort unit w speed vector value:

$$|w| = \sqrt{(\dot{X}_s)^2 + (\dot{Y}_s)^2} = \sqrt{\left[v - l' \cdot \cos\left(\frac{l'}{\lambda}t\right)\right]^2 + \left[l' \cdot \sin\left(\frac{l'}{\lambda}t\right)\right]^2}$$

(12)

The condition of the patrol unit beginning position allows to define the value of the position at the 0 time, particularly we will have:

$$X(0)_S = \lambda = u \cdot \Delta t + R \quad (13)$$

$$Y(0)_S = 0 \quad (14)$$

Operating in a similar way for the submarine, it will have a beginning position which can be determined as follows having shown with θ_0 the submarine attach beginning angle:

$$X(0)_{SUB} = \mathrm{v} \cdot \mathrm{T} + (\mathrm{R} + \mathrm{u} \cdot \mathrm{T}) \cdot \cos(\theta_0)$$

(15)

$$Y(0)_{SUB} = (\mathrm{R} + \mathrm{u} \cdot \mathrm{T}) \cdot \sin(\theta_0) \quad (16)$$

The equations (17) and (18) constitute, on the contrary, the parametric equations, in absolute coordinates of the submarine movement:

$$\dot{X}_{SUB} = -u \cdot \cos(\theta_0) \quad (17)$$

$$\dot{Y}_{SUB} = -u \cdot \sin(\theta_0) \quad (18)$$

The simplest of the parametric movement equations is that of the HVU unit moving with a rectilinear uniform movement along the x axe with v constant speed; in this way we have:

$$\dot{X}_{HVU} = v \quad (19)$$

$$\dot{Y}_{HVU} = 0 \quad (20)$$

Obviously we consider that the HVU starts from the coordinate origin. From the analysis of what said, we can obtain a first order differential equation system, to the ordinary derivatives, which can be easily solved through the integration with the Runge-Kutta method. In the Montecarlo simulation it will be simultaneously changed both the submarine angular position (attack angle) and the time within which the attack will take place to be able to compare the obtained result with that given by the theory. The termination condition of each simulation will be the first reached between the following two:

1. The submarine manages to reach the HVU at a minor or equal distance to R (successful attack) before to be intercepted by the patrol unit;
the patrol unit manages to reach the submarine (neutralized threat), before that this reaches the HVU at a shorter or equal distance to the PSR.

5.Conclusions

According to what analysed during the experimental campaign the scenario theoretical representation is confirmed by the simulation model, a particular attention should be paid to the Montecarlo scenario realisation since the sole attack angle randomisation does not solve the problem; it is really necessary to simultaneously proceed to the randomisation of the operation beginning distance as well as of the attack angle. Further improvements can be made by providing a randomized initialisation of the patrol unit position at time 0. The developed model makes possible to describe in a synthetic way the whole scenario from an analytic point of view by making possible the resolution of the same only in terms of numerical analysis.

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