A RAM SHIP-TO-SHIP COLLISION WHEN TRANSITING SUEZ CANAL

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SUMMARY

A ship-to-ship collision probability in transiting Suez Canal has been studied using the theoretical safety approach and an analytical model is revealed. The model adapts a collision scenario between the considered RAM-ship (the ship carrying radioactive material) and the colliding ship. The model estimates the probability of occurring an accident due to a collision between a RAM-ship or even a nuclear vessel with another colliding ship during its transit in Suez Canal. The model takes into consideration that the total probability of collision is the product of the collision probability by the conditional probability such that only one collision by one of the surrounding ships collides with the RAM-ship. The results are presented in a set of curves giving the estimated probability of collision for the considered nuclear vessel or a vessel carrying radioactive material with the other colliding ship versus the ships velocities. Moreover, the domain radius of the accident location around the considered nuclear vessel and the ship track angles are taken into considerations in the analysis and set as input variables. In the conclusions and discussions, recommendations to increase navigation safety in the future time of the Suez Canal have been determined.

INTRODUCTION

Suez Canal is an important water way for the international navigation. Its importance is referred to the fact that it is the longest (195 km) canal in the world without locks, and the navigation goes day and night. Also, it is liable to be deepened and widened, so it is widened in the recent years to become 365m in breadth at water top level. Moreover, the breadth between buoys is 180m. Besides, the canal is doubled over a distance of 68 km at the by-pass areas. These by-pass areas which are considered as double pass navigation routes are El-Ballah by-pass, El-Timsah by-pass, Deversoir by-pass and Kabreet by-pass(SCA 1995). However, since the transportation of the radioactive materials through Suez Canal and the number of the nuclear ships traversing it are increasing with a sensible rate every year, it is important to determine the probability of a RAM ship-to-ship accidental collision for the sake of safe navigation of this important water-way as well as to avoid radioactive contamination of an area inhabited by a high population density.

This paper deals with a theoretical approach to calculate the probability that one collision occurs in the accident domain area around the RAM ship during its transit in Suez Canal. The ships transit in the canal in three conveys daily ; two of them from Port-Saied to Suez at 0100 and 0700 hrs with at time span of six hours and the third convey from Suez to Port-Saied at 0600 hrs. On the average, a ship takes 15 hrs to transit the canal. Generally, a speed limit is imposed in the canal; it varies from 13 to 14 km/hr according to the category and the tonnage of ships, and in the southern sector it varies between 11 and 15 km/hr depending on the velocity and the direction of the tidal currents(SCA 1995). The probability of collision is thus estimated in two cases:

1) when both the considered RAM ship and the colliding ship are sailing in the same direction at any location -other than the double-route locations- along Suez Canal. At that location, the probability of collision is estimated twice according to the sailing direction; north-south and south-north directions, since the sailing speed limit varies with the sailing direction according to the velocity and direction of the tidal currents, and

2) when one of the two ships is sailing in an opposite direction to the other ship and it is estimated at a chosen by-pass location (namely; at the down-stream and the up-stream locations of El-Ballah by-pass location). It is chosen because it has the minimum navigation width of all other by-pass locations along Suez Canal.

THEORETICAL MODEL

Assuming that the accident occurs at a location **i** within an accident domain circle of radius R_i of which the considered RAM ship(or (NS)) is located at its center. Thus R_i can never be greater than the half width of Suez Canal at the corresponding location i.

If **V** is the sailing velocity of the concerned ship (NS) through the location **i**, and it takes time a_i to traverse the domain circle , and sails among a random distribution of ships of speed **U**. If one imagines that this circle of radius R_i with the NS placed at its center and moving with it, so the calculations can be performed to find the proportion of ships that will enter this circle in a given time. Figure (1) illustrates the area of ships entering that circle of radius R_i.

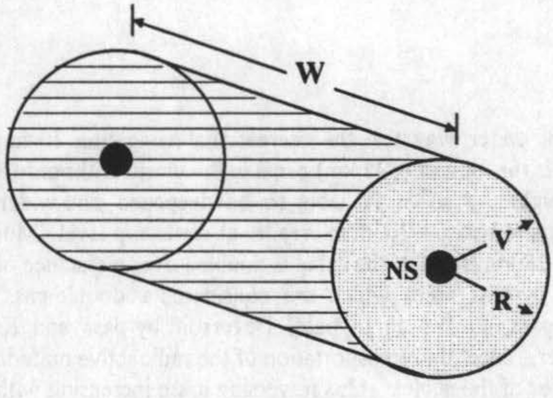


Fig.1 Area of Ships Entering The Moving Circle of Radius R

Now assuming that this NS is surrounded by ships with varying track angle α and that these track angles are uniformly distributed and independent of grid position **i**. If n_i is the average number of ships in a unit area per unit time, so the average number within track angles between α and $\alpha+d\alpha$ will be $(n_i \, d\alpha / 2\pi)$ with the other ships moving at speed **W** relative to the NS, given by:

$$W = (U^2 + V^2 - 2\, UV \cos \alpha)^{1/2} \qquad (1)$$

Therefore for such ships to enter the circle $\mathbf{R_i}$ in a unit time, they be in the shaded area - as shown in Fig.(1) - which has an area equals $\mathbf{2\,R_i\,W}$. The number of ships of track angles between α and $\alpha+d\alpha$ to enter the circle per unit time is given by (Koopmam 1956 and Minorsky 1976):

$$2\,R_i\,W\,n_i\,d\alpha\,/\,2\,\pi \qquad (2)$$

The total number to enter the circle $\mathbf{R_i}$ at location i per unit time is:

$$N_{oi} = 2\,R_i\,n_i\;\;W\,d\alpha\,/\,2\,\pi$$

$$= (R_i\,n_i/\,\pi\,)\int_0^{2\pi}(\;U^2 + V^2 - 2\,U\,V\cos\alpha\;)^{1/2}\,.\,d\alpha \qquad (3)$$

To perform this integration and for easiness of the calculations, Eq.(3) can be put in another final mathematical form to be:

$$N_{oi} = (4\,R_i\;n_i\,/\,\pi)\,(\,U{+}V\,)\int_0^{\pi/2}(\,1{-}\sin^2\sigma.\,\sin^2\phi\,)^{1/2}\,.\,d\phi$$

with $\phi = (\,\pi - \alpha\,/\,2\,)$, thus $\mathbf{N_{oi}}$ will be:

$$N_{oi} = \;(\,4\,R_i\,n_i\,/\,\pi\,)\,(\,U{+}V\,)\;E\,(\,\sigma\,) \qquad (4)$$

where $\sin\sigma\; = \;2(\,UV\,)^{1/2}/\,(U{+}V)$ and $E\,(\,\sigma\,)$ is the complete integral of the second kind (Abraouritz and Stegun 1964). Its analytical solution takes the form (Beyer 1972):

$$E\,(\sigma) = \;(\pi\,/\,2)\,(\,1{-}\,(1/2)^2.\,\sin^2(\sigma) - (1.3/2.4\,)^2.\,((\sin^2(\sigma))^2)/3$$
$$-\,((\,1.3.5\,)\,/\,(2.4.6)).\,((\,\sin^2(\sigma))^3)\,/\,5 - \ldots\ldots\ldots\;\text{if}\;\sin^2(\sigma){<}1 \qquad (5)$$

Now to estimate the probability of collision within circle R; if $\mathbf{K_i}$ represents the average number of collisions in a unit area/unit time, then the total number of collisions within the circle $\mathbf{R_i}$ per unit time $\mathbf{K_{oi}}$ is given by (Sharp and Minorsky 1977):

$$K_{oi} = K_i.\,2\,R_i\,W \qquad (6)$$

since by consistency: $2\,R_i\,W{=}\;N_{oi}\,/\,n_i = K_{oi}\,/\,K_i$

If $\mathbf{m_i}$ and $\mathbf{I_i}$ are random variables giving the number of collisions and ships respectively in location **i** while the **NS** is traversing it, if $F(m_i\;=\;K)$ and $G\;(\;l_i\;=L\,)$ represent the probabilities that are exactly **K** collisions and exactly **L** ships in **i** while **NS** is traversing it, then the total probability ($\mathbf{P_t}$) that **NS** will be in collision while traversing **i** given that **L** other ships are in the grid and **K** collisions occur is thus given by (Olkin et al 1994, Sharp 1977 and Ross 1993):

$$P_t = F(m_i = K)\;.\,G\,(\,l_i = L\,) \qquad (7)$$

Based on the assumption that the probability of more than one event occurring in a given instant is negligible, the total probability $\mathbf{P_t}$ can be estimated from Poisson distribution as (Devore 1995):

$$F(m_i = K) = \lambda_i \cdot e^{-\lambda i} \; / K! \qquad K > 0\,,\ \lambda_i > 0 \qquad (8)$$

$$G(l_i = L) = \mu_i \cdot e^{-\mu i} \; / L! \qquad L > 0\,,\ \mu_i > 0 \qquad (9)$$

where; $\mu_i = N_{oi} \cdot a_i$ = average number of ships other than NS in circle R_i durintraverse of **i** by NS,

$\lambda_i = K_{oi} \cdot a_i$ = average number of collisions other than NS in circle R_i during the traverse of **i** by NS,

$K_{oi} = 2\, R_i\, W.k_i$ = average number of collisions within circle R_i per unit time,

N_{oi} and **W** are given by Eqs.(4) and (1) respectively. Thus the total probability is given by:

$$P_t = (\lambda_i \cdot e^{-\lambda i} \; / K!) \cdot (\mu_i \cdot e^{-\mu i} \; / L!) \qquad (10)$$

and the total probability that exactly one ship - other than the NS - exists in location **i** and within circle **R** and performs exactly one collision with the NS during its traverse the location **i** (i.e. **L=1, K=1**) is given by:

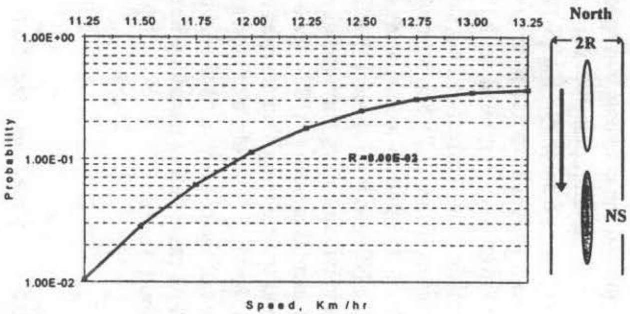
$$P_t = (\lambda_i \cdot e^{-\lambda i}) \cdot (\mu_i \cdot e^{-\mu i}) \qquad (11)$$

RESULTS AND DISCUSSIONS

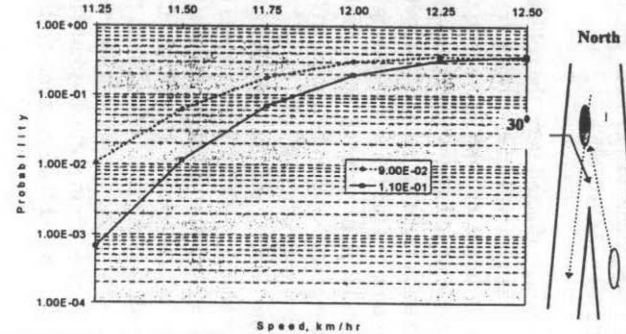
The previous analytical model has been programmed in FORTRAN language and applied to realistic data derived from Suez Canal Authority (SCA 1995) in order to determine the probability of collision of a RAM ship (NS) with another ship along Suez Canal at any by-pass location along the canal, and in order to determine the parameters affecting such probability.

Figure(2) shows the effect of the colliding ship speed on the probability of collision at a navigation radius Ri = 90m when it sails from north -to- south in the same direction following the nuclear ship which moves with speed = 11km/hr. This specified 90m figure of Ri represents exactly the navigation half width between the buoys along Suez Canal(SCA 1995). Also, Fig.(3) illustrates such probability of collision along the single route of Suez Canal when the colliding ship sails following the nuclear ship from south-to-north direction. As shown from the figures, the probability of collision increases as the colliding ship speed increases. It increases from 0.01 at colliding ship speed =11.25km/hr to 0.35 when the colliding ship speed reaches 13.00 km/hr when they sail from north-to-south direction, and it increases from 0.0017 to 0.35 when the colliding ship speed increases from 13.25 to 15.0 km/hr respectively when the convey directs from south-to-north. This means that the probability of collision becomes highly increased as the colliding ship speed reaches its upper limiting speed for the convey. In other words, to increase the navigation safety in the single route passes of Suez Canal, the convey ships upper speed limits should not exceed 11.5 Km/hr for the north-south convey direction and 13.5 Km/hr for the south-north convey direction. In such case the probability of collision does not exceed 0.03 and 0.01 respectively.

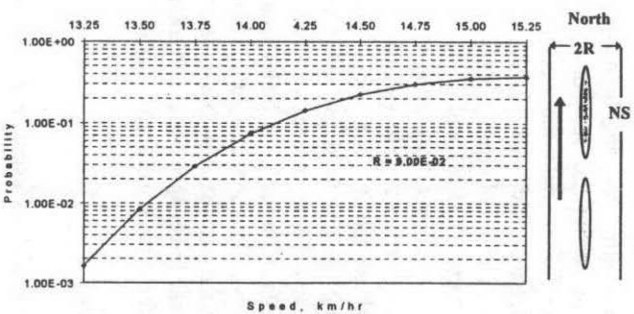
The effect of the colliding ship speed, the sailing direction of both colliding and nuclear ships and the track angle variations on the total probability of collision at El-Ballah by-pass location (both at its north and south sides) are all illustrated in Figs.(4) to (7). At each ,



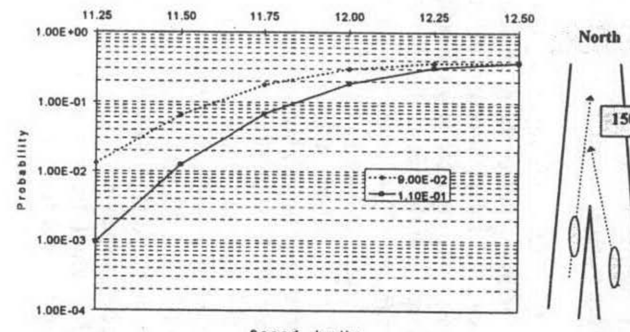
Fig(2) Variation of Collision Probability Versus Colliding Ship Speed at Navigation Radius R_i = 90 m With NS Speed = 11 km/hr When Both Ships Sail in Same Direction (α =180°) Along Suez Canal from North to South.



Fig(4) Collision Probability Versus Colliding Ship Speed at Navigation Radii R_i = 90m, 110m With NS Speed = 11km/hr When Both Ships Sail in Opposite Directions (inclined with α = 30°) At EL-Ballah By-pass North Location..



Fig(3) Variation of Collision Probability Versus Colliding Ship Speed at Navigation Radius R_i = 90 m With NS Speed = 13 km/hr When Both Ships Sail in Same Direction (α =180°) Along Suez Canal from South to North.



Fig(5) Collision Probability Versus Colliding Ship Speed at Navigation Radii R_i = 90m, 110m With NS Speed = 11 km/hr When Both Ships Sail in Same Direction (inclined with α = 150°) At El-Ballah By-pass North Location.

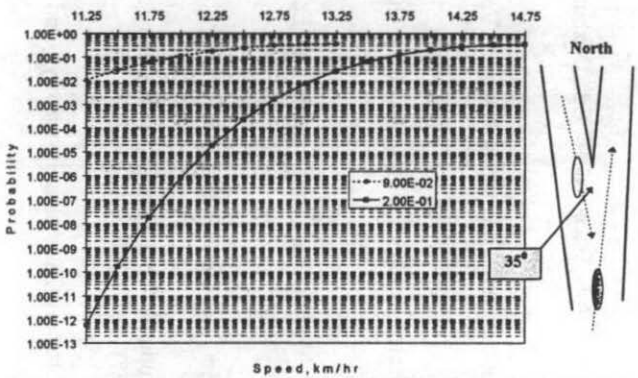
the probability is calculated and presented when Ri=90m (i.e. when the circle of collision lies between the buoys) and when Ri equals the half navigation width if the collision occurs just after the NS leaving or just before the NS entering the by-pass as schematically clarified on the figures. It is worth noting that data of both the track angle inclinations and the navigation width are measured from the Suez Canal realistic Map (SCA 1995).

As shown from the figures, the probability of collision is highly affected with the colliding ship speed and radius of the circle of collision while it is nearly unaffected with the track angle variation and the sailing direction of both ships. It increases with increasing the colliding ship speed and with decreasing the radius of the circle of collision whereas its value is constant irrespective of the ships sailing direction or the track angle variation. Moreover, as shown in Figs.(6) and (7), the total probability of collision when the NS is just leaving or just entering EL-Ballah by-pass south location (Ri = 200m) is nearly negligible (the order of magnitude is 10^{-13}) when both ships sails with the lower limit of the allowable convey speed limit whereas such probability increases to the order of magnitude of 10^{-3} to 10^{-4} at El-Ballah by-pass north location (Ri = 110m) as shown from Figs.(4) and (5). At this lower limit speed for the colliding ship to sail with, the total probability of collision increases by about 10^{10} times when the radius of the circle of collision reduces from 200m to be equal to the half width of the breadth between the buoys (i.e. 90m) as illustrated in Figs.(4) and (5). The factors affecting the total probability of collision; the radius of the circle of collision, the colliding ship speed when both ships sail in the same direction and the nuclear ship sails with speed = 13 km/hr (from south-to-north) and = 11km/hr (from north-to-south) are shown as probability charts in Figs. (8) and (9) at Port Saied and Suez harbors location respectively.

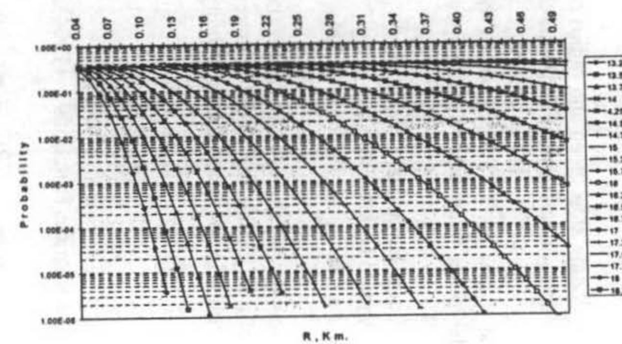
Generally, at Port Saied and Suez harbors - as shown from figures- the total probability of collision increases with increasing both the navigation radius and the colliding ship speed even if both ships sail in the same direction. However, at navigation radius 200m and at colliding ship speed of 15 Km/hr the probability of collision increases from 0.09 (Fig.(8)) to 0.3 (Fig.(9)) when the considered NS ship speed decreases from 13 Km/hr to 11Km/hr , i.e. lowers its speed. These collision probability values can be lowered or controlled with the aid of these charts (Figs.(8) and (9)) by exactly determining the corresponding safe navigation radii. Moreover, increasing the colliding ship speed from 13.25 Km/hr(lower speed limit at the north sector) to 14Km/hr (upper speed limit at the north sector) leads to increase the total probability from $3x10^{-5}$ to 0.05 when the NS sails with speed 13Km/hr (lower speed limit) and both ships sail in the same direction within a navigation radius of 110m. Also, at the southern sector, the total probability increases from $1x10^{-4}$ to 0.4 when the NS sails with the lower limit speed (11Km/hr) and the colliding ship changes its speed from the lower limit speed to the upper limit speed (15Km/hr) . Therefore to increase the navigation safety at these harbors, the upper speed limit of the convey ships should be kept constant at the lower speed limit and should not exceed its value during transiting Suez Canal, i.e. 11Km/hr in the north sector and 13 Km/hr in the south sector.

CONCLUSIONS

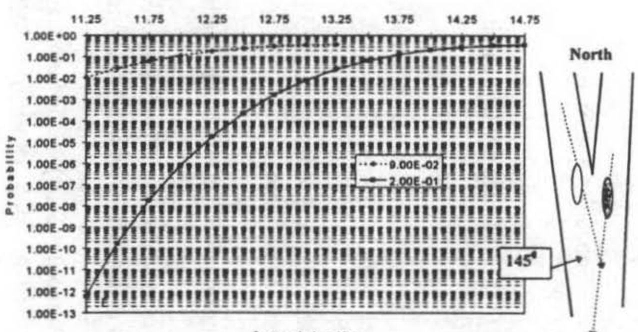
1. An analytical model to estimate a RAM ship (a ship carrying radioactive materials or a nuclear vessel (NS))-to-ship accident collision probability when both are transiting Suez Canal is developed taking into consideration that the total probability of collision is the



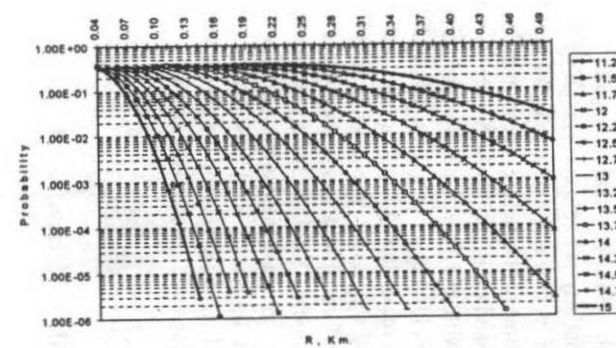
Fig(6) Variation of Collision Probability Versus Colliding Ship Speed at Navigation Radii R_i = 90m, 200 m With NS Speed = 11 km/hr When Both Ships Sail in Opposite Directions (inclined with $\alpha = 35°$) At El-Ballah By-pass South Location.



Fig(8) Probability of Collision Versus Navigation Radius R_i at Different Colliding Ship Speeds With NS Speed = 13 km/hr When Both Ships Sail in Same Direction ($\alpha = 180°$) At Port-Saied Port Location.



Fig(7) Variation of Collision Probability Versus Colliding Ship Speed at Navigation Radii R_i =90m, 200m With NS Speed = 11 km/hr When Both Ships Sail in Same Direction (inclined with $\alpha = 145°$) At El-Ballah By-pass South Location.



Fig(9) Probability of Collision Versus Navigation Radius R_i at Different Colliding Ship Speeds With NS Speed = 11 km/hr When Both Ships Sail in Same Direction ($\alpha = 180°$) At Suez Port Location.

product of the collision probability by the conditional probability such that only one collision by one of the surrounding ships collides with that RAM-ship.

2. The investigation has revealed on establishing collision probability charts governing the factors affecting such probability which enables in controlling the direction of ships transiting Suez Canal for the sake of safe navigation.

3. The probability of collision is highly affected with the colliding ship speed and radius of the circle of collision (or the navigation radius) while it is nearly unaffected with the track angle variation and the sailing direction of both ships.

4. The probability of collision becomes highly increased (reaches 0.5) when one of the ships sails with the lower allowed speed limit while the other ship sails with the upper allowed speed limit at a navigation radius of 100m.

5. So, to increase the navigation safety at Port Saied and Suez harbors and the double route passes, the upper speed limit of all convey ships should be kept constant at the lower speed limit and should not exceed its value during its transit, i.e. 11Km/hr in the north sector and 13 Km/hr in the south sector.

6. Also, to increase the navigation safety in the single route passes along Suez Canal, the convey ships upper speed limits should not exceed 11.5 Km/hr for the north-south convey direction and 13.5 Km/hr for the south-north convey direction. In such case the probability of collision does not exceed 0.03 and 0.01 respectively.

REFERENCES

Abraouritz, M. and Stegun, I. A. (Eds.);" Handbook Of Mathematical Functions", (1964).

Beyer, W.H. (Ed.); " CRC Handbook Of Mathematical Science ", CRC Press., Inc., Florida, USA (1972).

Devore, J.L.; " Probability And Statistics For Engineering And Sciences", 4th Ed., Duxbury Press. ,N.Y. (1995).

Koopman, B.O.; " The Theory Of Search, I. Kinematic Bases", Operations Research, Vol. 4, No. 2 (1956).

Minorsky, V. U.; "Probability Of Collision On Selected Routes", NTIS MA- RD- 920-77021, Vol.1 (1976).

Olkin, I.Derman, C. And Glester, L.; " Probability Models And Applications", 2nd Ed., McMillan Press., N.Y. (1994).

Ross, Sh.; " Introduction To Probability Models", 5th Ed., Academic Press., N.Y. (1993).

Sharp, G.G. and Minorsky, V.U.; " Ship Accident Studies", Proc. Symposium on Safety of Nuclear Ships , Hamburg, OECD, IAEA , Vienna (1977).

Suez Canal Authority (SCA); " The Suez Canal; A Waterway Channeling Prosperity", and " The Suez Canal Map", SCA, Ismaiellya, Egypt (1995).

SESSION 15.3

Plutonium Transport