EVALUATION OF ALLOWANCE TIME FOR COMMENCEMENT OF THE CLOSE QUARTERS AVOIDANCE MANOEUVRE

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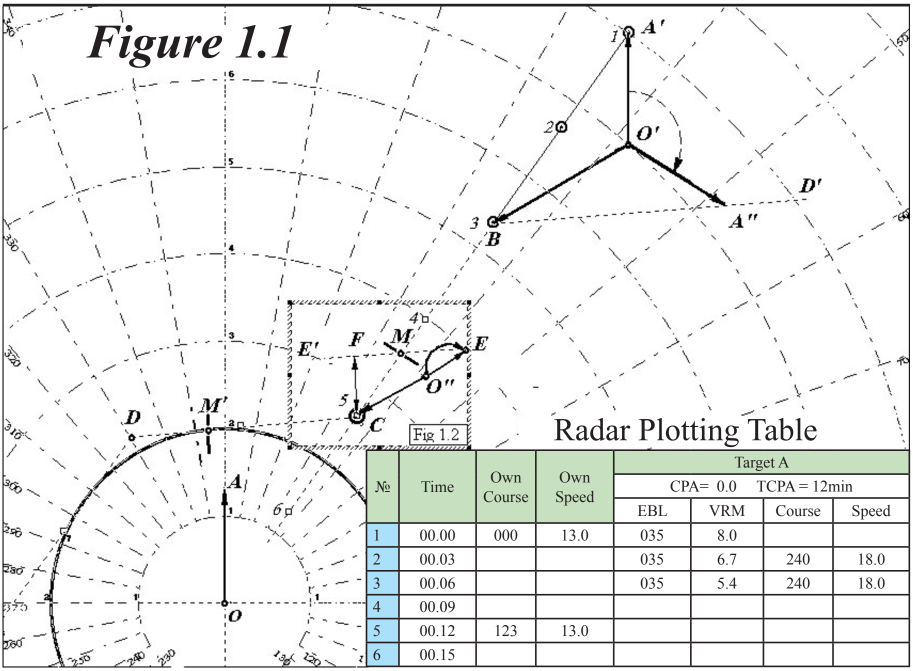
While making the decision for any action to avoid close quarters situation the navigator must evaluate the manoeuvrability of the vessel for the commencement of the manoeuvre. Very simple and convenient methods recommended for the alteration course alone and alteration speed alone manoeuvres explained with the illustrations. The algorithms and the equations systems developed for obtaining the results of this article may be used for calculation of close quarters avoidance manoeuvre as in the operational ARPA and VTS systems as in the developing ones.

Keywords: allowance time, close quarters avoidance, avoiding collision, safety maneuver calculation, vessel traffic management

While making the decision for any action to avoid close quarters situation the navigator must evaluate the manoeuvrability of the vessel for the commencement of the manoeuvre.

Let's consider the standard calculation procedure of the alteration of course alone using radar plotting. In Figure 1.1 own ship proceeds with the course 000˚ and speed 13.0 kt. Data of the first three points of the observation performed in the Radar Plotting Table and plotted in Figure 1.1 as points 1, 2, 3. As a result of the computing the data of the first three points received CPA = 0.0 and TCPA = 12.0 min from the third point of observation.

Our ship safety distance installed as 2 miles. The circle of the two miles radius performed in Figure 1.1 around the center of the own ship *O*.



№	Time	Own Course	Own Speed	Target A			
				CPA= 0.0 TCPA = 12min			
				EBL	VRM	Course	Speed
1	00.00	000	13.0	035	8.0		
2	00.03			035	6.7	240	18.0
3	00.06			035	5.4	240	18.0
4	00.09						
5	00.12	123	13.0				
6	00.15						

For the calculation of the alteration of course alone manoeuvre in the anticipated 5^{th} point of the plotting (marked as point *C* in Figure 1.1) the following standard procedure is to be used:

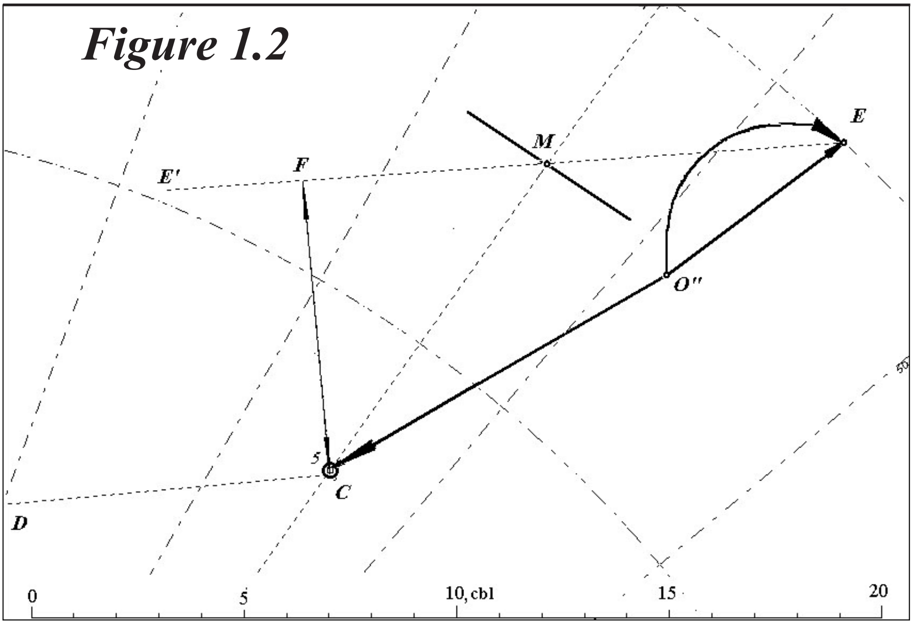
- Draw six-minutes vector of the own speed *OA* of 13 cbl. length.
- Draw parallel vector to the above *O'A'* of the same length with the end of this vector directed into the first point of the observation.
- Draw six-minutes vector of the target speed *O'B* from the beginning of the vector *O'A'* into the third point of the observation and get target course 240° and target speed 18.0 kt.
- Draw the line *CD* touched on the circle *O* anticipated to be the estimated line of the relative motion of the target after own ship manoeuvre.
- Draw the line *BD'* through the third point of the observation parallel to *CD*.
- Turn around vector *O'A'* to starboard until crossing the line *BD'* and obtain six-minutes vector of the own ship movement for giving wide berth *O'A''* and get to alter the course of our ship to 123°.

Needless to say that the command to start altering course has to be done earlier than the target reaches the estimated point *C* in relative motion. If the diameter of circulation of the own ship is 1000m (5.4 cbl.) the time of altering course to 123˚ is estimated to be 3.1 min.

On the other hand if the command to start altering course should be done at the time of 3.1 min before the target reached the estimated point *C* in relative motion the CPA after course alteration should be differrent from originally estimated as far as the target at the end of the manoeuvre occurred not to be in the estimated point *C* but in some other point determined by manoeuvrability of the own ship and geometry of the encounter.

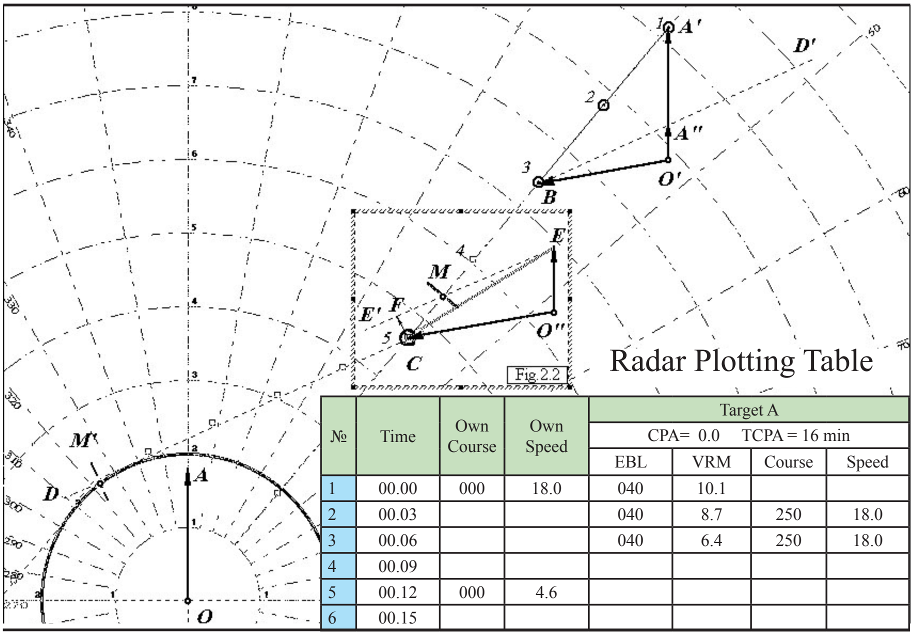
For more precision evaluation of the manoeuvre commencement time by the own ship let's do some drawing in the rectangle allocated in Figure 1.1 around the point *C* and increased in Figure 1.2:

- Draw the vector *O"C* parallel to the vector of the target speed *O'B* directed into the estimated point *C* and the length of 9.3 cbl. (the way which the target will proceed while the own ship is altering course for 3.1 min.).
- Draw the vector *O"E* from the point *O"* which performed the true movement of the own ship at the end of alteration course to 123˚.



- Draw the line *EE’* parallel to the new estimated line of the relative motion *CD* until crossing with the original line of the relative motion *BC* in the point *M*; the point *M* is the point where the command to start altering course bythe own ship should be done.

Thus we found that the command to start altering course on the own ship has to be done at 9 cbl.(or 1.7 min) before the target is to reach the estimated point *C* in relative motion. Should the command to start altering course on the own ship be done exactly in the estimated point *C* the CPA error occurred to be 7.8 cbl.(the length of the perpendicular *CF* in the Figure 1.1 and in the Figure 1.2). This value is comparable with the installed CPA limit of 2.0 miles and in other circumstances may produce the dangerous situation.



№	Time	Own Course	Own Speed	Target A			
				CPA= 0.0 TCPA = 16 min			
				EBL	VRM	Course	Speed
1	00.00	000	18.0	040	10.1		
2	00.03			040	8.7	250	18.0
3	00.06			040	6.4	250	18.0
4	00.09						
5	00.12	000	4.6				
6	00.15						

If the command to start altering course on the own ship is done in the point *M* the target should proceed with the estimated safety CPA and should return to the original line of the relative motion after command on our ship to return to the original course in the point *M’* (calculated in the same way).

Let’s consider the similar situation for the alteration of the speed alone. In Figure 2.1 own ship proceeds with the course 000˚ and speed

18.0 kt. Data of the first three points of the observation performed in the Radar Plotting Table and plotted in the Figure 2.1 as points 1, 2, 3.

As a result of the computing the data of the first three points received CPA = 0.0 and TCPA = 16.0 min from the third point of the observation.

The standard procedure is the same as the previously performed with the only difference that new speed in the Figure 2.1 is to be obtained as the vector *O'A"* with the beginning in the point *O'* and with the end at the crossing of the vector of the original speed *O'A'* and the line *BD'* parallel to the estimated line of the target relative motion after own ship manoeuvre.

Similarly we find the target course as 250° and target speed 18.0 kt. The new speed for own ship for giving the wide berth has to be 4.6 kt.

Needless to say that the command to start reducing speed should be done earlier than the target reached the estimated point *C* in relative motion. If the time of the speed free slow down from 18.0 kt to 2.0 kt is 25.6 min (corresponding to the way of the speed free slow down 9.6 cbl.) the time of the speed slow down from 18.0 kt to 4.6 kt is estimated as 9.3 min (without using reverses).

On the other hand if the command to start reducing the speed should be done at the time 9.3 min (i.e. near the second point of radar plotting observation) before the target reached the estimated point *C* in relative motion the CPA after speed reducing should be differrent from originally estimated as far as the target at the end of the manoeuvre occurred not to be in the estimated point *C* but in some other point determined by manoeuvrability of the own ship and geometry of the encounter.

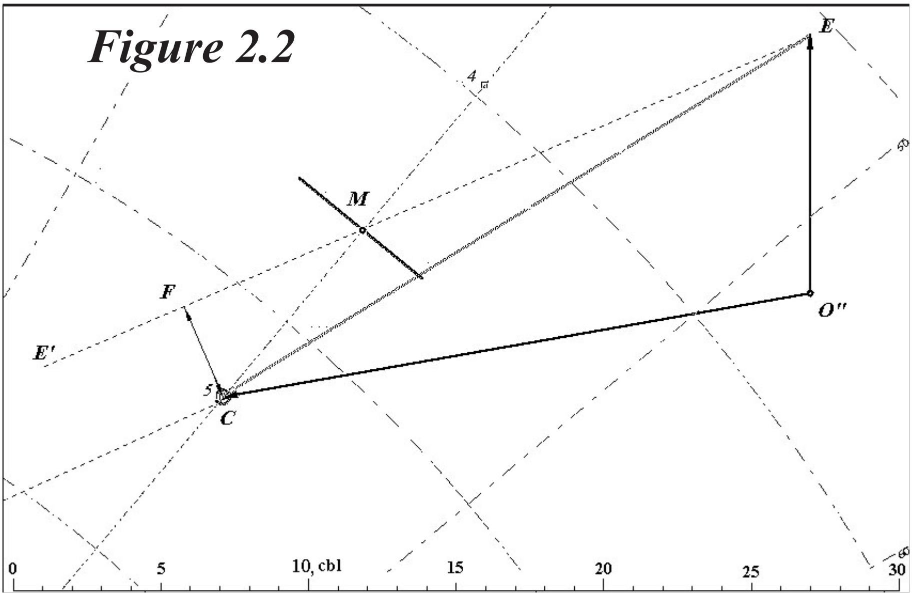
For more precise evaluation of manoeuvre commencement time of the own ship let's do some drawing in the rectangle allocated in the Figure 2.1 around the point *C* and increased in the Figure 2.2:

- Draw the vector *O"C* parallel to the vector of the target speed *O'B* directed into the estimated point *C* and the length of 27.9 cbl.(the way which the target proceeds in 9.3 min. while the own ship is reducing the speed down to 4.6 kt.).

- Draw the vector *O"E* with the length of 8.5 cbl. from the point *O"* which performed the true movement of the own ship at the end of the reducing speed to 4.6 kt.

- Draw the line *EE'* parallel to the new estimated line of the relative motion *CD* until crossing with the original line of the relative motion *BC* in the point *M*; the point *M* is the point of the command to start reducing the speed on the own ship to be done.

Thus we found that the command to start reducing the speed on the own ship has to be done at 7.5 cbl. (or 1.6 min) before the target reaches the estimated point *C* in relative motion. Should the command



to start reducing the speed on the own ship be done exactly in the estimated point *C* the CPA error occurred to be 4.0 cbl. (the length of the perpendicular *CF* in the Figure 2.1 and in the Figure 2.2). This value is comparable with the installed CPA safety limit of 2.0 miles and in other circumstances may produce the dangerous situation.

If the command to start reducing the speed on the own ship is done in the point *M* the target should proceed with the estimated safety CPA and should return to the original line of the relative motion after command on our ship to increase the speed up to the original one in the point *M'* (calculated in the same way).

Of course it is not possible to make such calculations in real conditions of sailing at sea and the scale of radar plotting is not fit for the drawings performed.

A simple and effective way of the allowance time evaluation for the close quarters avoidance manoeuvre commencement has been luckily found. The systems of the equations and algorithms have been developed for the ships' encounter situations. Various combinations of encounter have been examined with special programs.

Analysis and comparison of the numerous situations with all sorts of speeds of the own and target ships, geometry of encounters and the angles of the course alteration afforded to produce the equation (1) of the evaluation of the allowance time for the commencement of the close quarters avoidance manoeuvre by alteration course alone:

$$T_{alw} = 0.7 \cdot T_{man}\ , \qquad (1)$$

where:

T_{alw} - the allowance time for the alteration course alone manoeuvre, min;

T_{man} - the time from the beginning of the course alteration up to the completing the turn up to the given course, min (to be obtained from the ships' manoeuvring tables or from the equivalent calculations).

In the former performed situation in the Figure 1.1 and Figure 1.2 $T_{man} = 3.1\ min$, and time allowance $T_{alw} = 0.7 \cdot 3.1 \approx 2.0\ min$.

The equation (1) has been checked for the own ship and target course differences from 010° up to 350° with 010° interval for own ship alteration course from 030° up to 120° with 030° interval in the range of own and target ship velocities from 5kt. up to 35 kt. with 5kt.interval in all sorts of combinations.

With the test above it was found that for the vessel with the diameter of circulation 1000m (5.4 cbl.) in all these combinations the CPA error does not exceed 1cbl. This is acceptable in the real sailing conditions if the manoeuvre is performed in ample time.

The analysis of the alteration speed alone situations show that the allowance time for the commencement of the close quarters avoidance manoeuvre by alteration speed alone does not depend on the geometry of the encounter and on the speed of the target ship and may be calculated with the equation (2):

$$T_{alw} = \frac{S_{\text{man}} - T_{\text{man}} \cdot V_{\text{man}}}{V_0 - V_{\text{man}}} \quad , \qquad (2)$$

where:

T_{alw} – the allowance time for the alteration speed alone manoeuvre, measured in minutes;

T_{man} – the time from the beginning of the speed alteration to the completing of reducing velocity down to given speed, min (to be obtained from the ships' manoeuvring tables or from the equivalent calculations);

S_{man} – the way in true motion from the beginning of the speed alteration to the completing of velocity reducing down to given speed V_{man}, cbl (to be obtained from the ships' manoeuvring tables or from the equivalent calculations);

V_0 – initial speed of the own ship, cbl./min;

V_{man} – reduced speed of the own ship calculated for the manoeuvre, cables per minute.

The analysis of the equation (2), if no reverses expected, afforded to make the Table 1 below:

Table 1. Equation (2) analysis results

Percent of reducing the original speed V_0 down to calculated speed V_{man}	Allowance time evaluation for commencement of the close quarters avoidance manoeuvre by alteration speed alone without reverses
75% - 90%	$T_{alw} = 0{,}3 \cdot T_{man}$
20%-75%	$T_{alw} = 0{,}2 \cdot T_{man}$
20% and less	$T_{alw} = 0{,}1 \cdot T_{man}$

For the former simulated situations in Figure 2.1 and Figure 2.2 $T_{man} = 9.3\ min$, percent of reducing speed from 18.0 kt. down to 4.6 kt. is 36% and time allowance $T_{alw} = 0{,}2 \cdot 9.3 \approx 1.8\ \ min$.

The equations (1) and (2) as well as Table 1 are to be used in the conditions the same as for the ships' manoeuvring tables. Usually it means the current less than 1 kt., sea wave height up to 0.5 m, wind up to 5 m/s. In poor weather conditions the application of the equations (1) and (2) and Table 1 may be severely restricted especially with the small speed vessel to manoeuvre.

It is also understood that the equations (1), (2) and Table 1 are just applicable to the collision avoidance actions taken in ample time and with due regard to the observance of good seamanship.

The algorithms and the systems of the equations developed for obtaining the results of this article may be used for calculation of close quarters avoidance manoeuvres in the working and in the developing ARPA and VTS.

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