Model of Optimal Collision Avoidance Manoeuvre on the High Seas to Improve Safety at Sea

Model optimalnog manevra izbjegavanja sudara na otvorenom moru s ciljem poboljšanja sigurnosti

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Summary

Collision of ships is the most frequent accident in modern navigation. Provision of up-to-date navigational equipment does not automatically mean fewer collisions. As a matter of fact, there are more collisions because the number of vessels is constantly increasing. Due to the increased traffic density vessels meet at shorter distances, so they have very little time and space left for appropriate collision avoidance manoeuvre. The Collision Avoidance Rules themselves do not represent sufficient guarantee to avoid collisions, since the researches made in the human factor showed that 10 % of all collisions were caused by non compliance with the Rules and 90 % by other human errors. Furthermore, collisions are basically not caused by inadequate interpretations of the Rules, but above all, by wrong interpretations of the situations taking place at sea. This is the consequence of insufficient training on RADAR and Automatic Radar Plotting Aids, and particularly of misinterpretation of the results of radar plotting procedures. Generally all accidents of ships can be divided into two basic categories. First, accidents in which measures for damage control should be taken immediately, and second, those which require a little more patient reaction. And the fact that collisions belong to the first category has encouraged writing of the current paper. The proposed model of optimal collision avoidance manoeuvre. of ships on the basis of electronic data collection was made by means of the navigation simulator NTPRO – 5000.

KEY WORDS

Safety at Sea
Collision Avoidance System
Starting Point of Collision Avoidance Manoeuvre

Sažetak

Sudar brodova je najčešća nezgoda u modernoj navigaciji. Opremljenost modernom navigacijskom opremom ne znači automatski manje sudara. Naime, ima više sudara jer broj brodova neprestano raste. Zbog povećane gustoće prometa, brodovi se susreću na manjoj udaljenosti, tako da imaju malo vremena i prostora ostavljenog za prikladni manevar izbjegavanja sudara. Pravila izbjegavanja sudara sama po sebi ne prestavljaju dostatno jamstvo izbjegavanja sudara, budući su istraživanja o ljudskom čimbeniku pokazala da je 10% svih sudara uzrokovano nepoštivanjem Pravila, a 90% ostalim pogreškama ljudi. Nadalje, sudari osnovno nisu uzrokovani neadekvatnom interpretacijom Pravila, nego najviše krivom interpretacijom situacija koje se odvijaju na moru. Ovo je posljedica nedostatne RADAR i ARPA obuke i posebno loša interpretacija rezultata procedura radarskih ucrtavanja. Općenito, sve nezgode brodova mogu se podijeliti u dvije osnovne kategorije. Prvo, nezgode u kojima mjere za kontrolu štete trebaju biti poduzete odmah, i drugo, one koje zahtijevaju strpljiviju reakciju. A činjenica da sudar pripada u prvu kategoriju potaknuo je pisanje ovog priloga. Predloženi model optimalnog manevra izbjegavanja sudara brodova na temelju elektroničkog prikupljanja podataka izvršen je putem navigacijskog simulatora NTPRO – 5000.

KLJUČNE RIJEČI

sigurnost na moru
sustav izbjegavanja sudara
početna točka manevra izbjegavanja sudara

INTRODUCTION / *Uvod*

Collision of ships is the most frequent accident in modern navigation. Provision of up-to-date navigational equipment does not automatically mean fewer collisions. As a matter of fact, there are more collisions because the number of vessels is constantly increasing. Due to the increased traffic density vessels meet at shorter distances, so they have very little time and space left for appropriate collision avoidance manoeuvre.

The Collision Avoidance Rules themselves do not represent sufficient guarantee to avoid collisions, since the researches made in the human factor showed that 10 % of all collisions were caused by non compliance with the Rules and 90 % by other human errors. Furthermore, collisions are basically not caused by inadequate interpretations of the Rules, but above all, by wrong interpretations of the situations taking place at sea. This is the consequence of insufficient training on RADAR and Automatic Radar Plotting Aids, and particularly of misinterpretation of the results of radar plotting procedures.

The current paper aims to work out a safe and controlled collision avoidance manoeuvre, which complies with the Collision Avoidance Rules and is efficiently applied in navigation at sea. It also aims to enhance the safety of merchant shipping in general.

THEORETICAL PART / *Teoretski dio*

Radar plotting is a graphical display of the movements of objects observed on the radar screen and plotted on the radar diagram.

Radar plotting is used to:

- avoid collisions at sea during voyage by altering own ship course,
- avoid collisions at sea during voyage by altering own ship speed,
- avoid collisions at sea during voyage by altering own ship course and speed,
- calculate the course (Kt) and speed (bt) of the observed target vessel,
- predict manoeuvres of observed ships.

We distinguish two types of radar plotting:

- relative,
- absolute.

Relative radar plotting / *Relativno radarsko ucrtavanje*

In relative radar plotting we are first interested in the course and speed of the observed vessel that can be obtained from the vector triangle of speed, see Figure 1.

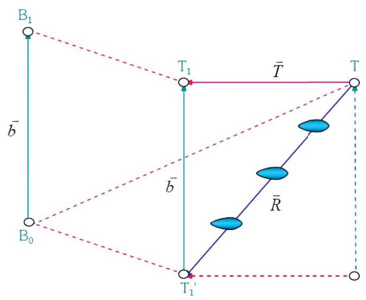

Figure 1 Relative and Absolute Radar Plotting
Slika 1. Relativno i apsolutno radarsko ucrtavanje

Collision Course / *Sudarni kurs*

If observing the relative vector $\vec{R}$, we see that the collision situation takes place when the relative vector passes through own ship or the centre of the radar screen, see Figure 2.

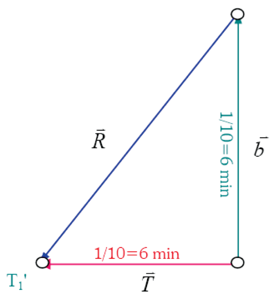

Figure 2 Vector triangle of speed
Slika 2. Vektorski trokut brzine

In both cases the bearing of the observed ship does not alter and the distance is decreasing.

Avoidance manoeuvre can be carried out in three ways:

- by altering course at same speed,
- by altering speed at same course,
- by altering speed and course.

In principle we avoid collisions on the high seas by altering course at same speed. Whereas altering speed at same course is applied in areas where manoeuvring space is limited and where engine is in standby position. In such case speed is decreased. Collision avoidance by altering course and speed is applied only in exceptional circumstances.

Manoeuvring Time (Mt) / *Vrijeme manevriranja*

The collision avoidance manoeuvre should be carried out instantaneously in time determined with the Action Point Time (APT). In such case mathematical calculations of our vector triangle will be accurate. Because of the ship's inertia her course and speed cannot be altered momentanneously. Therefore the manoeuvre of altering course and speed should start a little before APT and finished a little after APT. Thus, presuming a linear alteration of course or speed, APT would fall in the middle of the manoeuvre.

Some nautical tables give values "X" in metres, for which we have to start manoeuvre of altering course K_1, so that the ship will be on course K_2 after the manoeuvre. From the tables we obtain the value X with the arguments $\Delta K = K2 - K1$ and the radius of the turning circle, which differs with each ship and speed. The way of determining the starting point of manoeuvre with the value X is shown on figure 3.

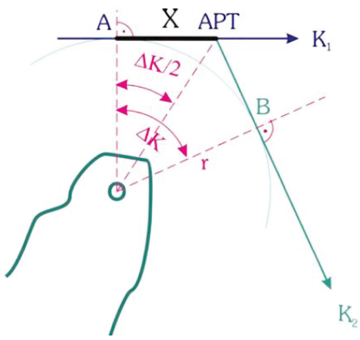

Figure 3 Determining the start of manoeuvre
Slika 3. Određivanje početka manevra

Avoidance manoeuvres will not be mathematically correct also for two reasons:

- in avoidance by altering course the ship's speed decreases relative to the helm movement. Thus the manoeuvre is practically carried out, but mathematically it is inaccurate,
- due to inaccurate plotting our results are mathematically imprecise .

CPA and TCPA of two Observed Targets / *Najbliža točka približavanja i vrijeme najbliže točke približavanja dvaju promatranih ciljeva*

When observing targets on the radar screen we are not interested only in their movement relative to own ship, but also their movement relative to each other. However, if we know what will be the distance of their passing, we can anticipate their eventual alteration of the course or speed, which may influence our future manoeuvre.

The avoidance manoeuvre at a definite CPA should be carried out early enough. The closer to the CPA circle the APT is located the major alteration of course is necessary to pass the target at a definite distance. The necessary course alteration can reach up to 90°, which however is not supported by some ARPA or simulator software, and in such case the whole system is blocked.

From this we can draw two conclusions:

- avoidance manoeuvre for a relevant CPA must start on time,
- if the observed target approaches too close to the CPA circle, the CPA condition should be reduced.

EXPERIMENTAL PART / *Eksperimentalni dio*

At a definite critical distance due to limited time to the CPA the officer on watch has the last chance to realise emergency procedure, which depends on the ship's manoeuvring characteristics and the officer's competence to carry out graphical or ARPA assisted plotting. In other words the safe passing distance must be longer than the distance which would prevent risk of collision above all due to uncontrolled and unexpected manoeuvres of other ships. Prudence and own ship are two elements, which the officer on watch should always keep in mind. International Regulations for Preventing Collisions at Sea define all actions that should be carried out by both ships in all passing situations. Unfortunately even a reasonable and competent officer on watch cannot assure that the other ship would act reasonably, safely and in the spirit of good seamanship.

Computerised Dynamic Ship's Model / *Kompjuterizirani dinamički brodski model*

The computerised dynamic ship's model is a computer program, which calculates the movement of each individual simulated ship in real time. It is based on the actions of navigating officers and the conditions affecting the ship. Momentary conditions, such as depth, current speed etc. can be computed from the current ship's position. They are supplied to the dynamic model together with the bridge orders (helm, main propulsion control etc.)[1]. The dynamic model does not comprise only the hydrodynamic characteristics of the hull but also the models for the ship's navigation instruments, i.e. main propulsion or steering gear. The main output of the dynamic model is the ship's movement, but we mathematically calculate also the value of the signal from the navigation instruments on the navigating bridge (RPM, helm position).

In making a model of optimal avoidance manoeuvre we used a computerised dynamic model of a real bulk carrier (M/V Jargara). The results were tested also on the ship *Laho* in the Bay of Koper.

Defining Elements and Condition / *Odlučujući elementi i uvjeti*

In the International Regulations we often come across the word *may*, which is understood as optional. The Master Judovič gives in his paper the case of the rudder angle to 70° (such angle is necessary for the ships to approach at a desired CPA), where with the help of the angle turning speed, delay in alteration of the rudder position[2], approaching speed and by adding the desired CPA, he got the distance at which he should start the avoidance manoeuvre at the latest [1].

For the purpose and aim of the research (simplification of procedures) we decided to substitute the following elements in the collision avoidance manoeuvre in order to preserve the desired passing distances (table 1).

Table 1 Substitution of avoidance manoeuvre elements
Tablica 1. Supstitucija elemenata manevara izbjegavanja sudara

ELEMENT	JUDOVIČ, A. B.	AUTHOR
Constant	CPA	Limited Point of Approach (LPA)[3]
Variable	Angle turning speed, delay in alteration of rudder position	Tactical Diameter (TD)
Variable	Approaching speed of ships	Degree of Collision Risk (DCR)

Impact of rudder angle or speed[4] on the tactical diameter is shown on figure 4.

Alteration of rudder angle or speed causes different values of the tactical diameter that have to be considered in manoeuvring.

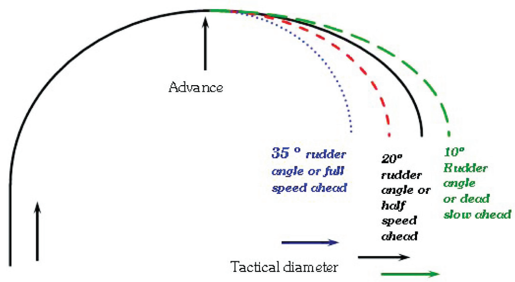

Figure 4 Impact of rudder angle or speed
Slika 4. Utjecaj kuta kormila ili brzine

Justification of DCR alteration[5] with approaching speed was confirmed by the simulation method (figures 5, 6, 7 and 8).

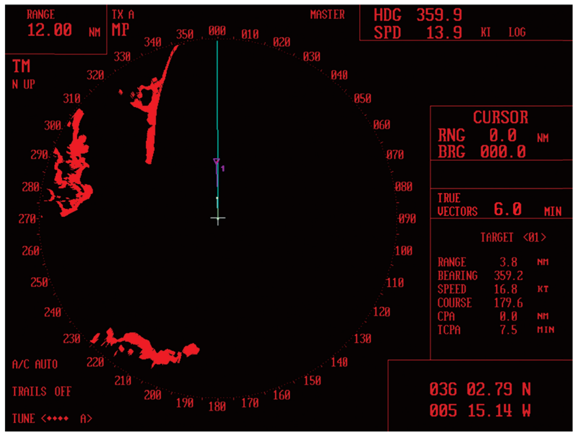

Figure 5 Degree of collision risk at approach angle 000°
Slika 5. Stupanj rizika sudara pri kutu približavanja od 000°

[1] The computerized model for the carriage of bulk cargo is in accordance with the resolutions: A.751(18) Interim Standards for Ship Manoeuvrability, passed in November 1993 and A.325(IX) Machinery Installations, passed in November 1975.

[2] "... considering the angle turning speed 1°/s and the delay in alteration of the rudder, which together takes 2 minutes, we need about 3-3,5 minutes for 70° rudder angle, which means the distance of about 1,5 Nm at the approach speed of 27 knots (4,5 cables per minute). Further, by adding the desired CPA – 1 Nm the calculation shows that the latest start of the collision avoidance manoeuvre should be at the distance 2,5 Nm"... [1].

[3] Limited point of approach is marked with the abbreviation LPA and it represents the distance at which is located the observed vessel while abeam of own vessel, either on port or starboard side. In practice it is believed that the manoeuvre has been executed successfully when the ship is at the desired safe distance [2]. This is usually when the avoided ship is abeam of own ship, as at this point the returning to the original course can already start.

[4] Here the angle turning speed and the delay in alteration of rudder are already considered, as the tactical diameter is the function of speed.

[5] The degree of collision risk is proportional to the size of collision course.

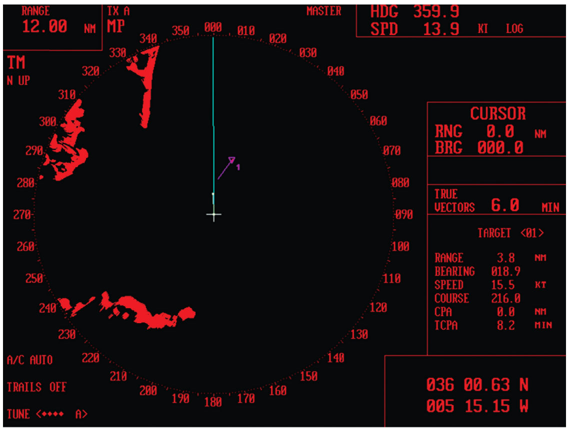

Figure 6 Degree of collision risk at approach angle 036°

Slika 6. Stupanj rizika sudara pri kutu približavanja od 036°

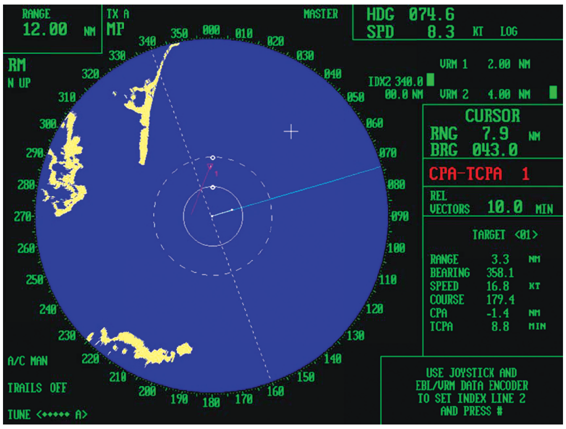

Figure 7 Start of manoeuvre at distance 4 Nm at approach angle 000°

Slika 7. Početak manevra na udaljenosti od 4 Nm pri kutu približavanja od 000°

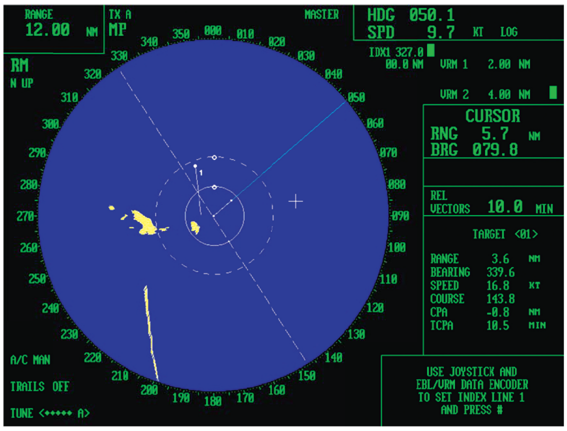

Figure 8 Start of manoeuvre at distance 4 Nm at approach angle 324°

Slika 8. Početak manevra na udaljenosti od 4 Nm pri kutu približavanja od 324°

Simulation / *Simulacija*

Instead of seven or eight [3], we used five different situations. Thus we reduced incomprehensibility of some situations. Table 2 shows the values of individual elements, necessary to make real collision scenarios. The table below was used as the basis for making a model of optimal avoidance manoeuvres of various collision scenarios.

Table 2 Degree of collision risk

Tablica 2. Stupanj rizika sudara

Collision course (°)	Course of target observed (°) PORT	STARBOARD	Approach angle (°)	Degree of collision risk
180 – 144	000 – 144	180 – 216	000 – 036	5
144 – 108	144 – 108	216 – 252	036 – 072	4
108 – 072	108 – 072	252 – 288	072 – 108	3
072 – 036	072 – 036	288 – 324	108 – 144	2
036 – 000	036 – 000	324 – 000	144 – 180	1

Numbering was made according to the degree of risk of collision considering two auxiliary hypotheses:

- wider collision angle – higher relative speed of target observed – greater risk of collision,
- narrower collision angle – higher relative speed of observed target – greater risk of collision.

Table 3 compares elements of avoidance manoeuvre. This served us to make the algorithm of optimal avoidance manoeuvre considering the desired approach distance:

LPA + TD *DCR = *LSD (Latest starting distance)*[6]

Further we shall try to verify the said formula by simulating manoeuvring characteristics of the computerised model of a real bulk carrier. The formula is confirmed relative to the criterium of the beam line position that must be equal to the algorithm - LPA. In our case the LPA will be 2 Nm. Due to repetition of data, simulation will be carried out at lower limits of sectors. In case of ambiguity or limitations of the navigation instruments, such as deleting of observed target on the radar screen, we would simulate in the area of the individual sector.

Table 3 Comparison of avoidance manoeuvre elements

Tablica 3. Usporedba elemenata manevra

Element	JUDOVIČ, A. B.	AUTHOR
Turning angle speed for 70° turning (A)	1°/s * 70° (70 s = 1.1666667 min)	
Angle turning speed and delay in alteration of rudder position (B)	2 min	Tactical diameter (TD)
A + B = C	3,2 min	
Approach speed (D)	27 Nm (4,5 cables per minute) * C = 14,4 k/m (1,4 Nm)	TD * SNT
CPA (1,0 Nm)	D + CPA = 2,4 Nm	+ MOS
Distance of manoeuvre starting	D + CPA	MOS + TP * SNT

Collision avoidance manoeuvre will be carried out in accordance with the Rule 8, i.e. *"be positive, made in ample time and with due regard to the observance of good seamanship"*. We shall also consider Rule 15, providing: *"... If the circumstances of the case admit, avoid crossing ahead of the other vessel".* Considerable course alterations are more appropriate, as they are easily seen and they may directly affect the choice of the right collision avoidance strategy of other ship. It should be taken into consideration that the changes of relative movement on the radar screen are always minor than the actual course alterations. If circumstances permit, we should avoid maximal rudder angles during manoeuvring in real situations. Tables 4 and 5 show calculated starting points of manoeuvre at 35° and 10°.

[6] Distance at which we must start manoeuvring at the latest.

Table 4 Starting point of manoeuvring at maximal rudder angle (35°)

Tablica 4. Početna točka manevriranja pri maksimalnom kutu kormila (35°)

Degree of collision risk	Approach angle (°)	TD	Formula	Starting point of manoeuvring (Nm)
5	000 036/324	0.34 0.34	2+0.34*5	3.7
4	036/324 072/288	0.34 0.34	2+0.34*4	3.36
3	072/288 108/252	0.34 0.34	2+0.34*3	3.02
2	108/252 144/216	0.34 0.34	2+0.34*2	2.68
1	144/216 180	0.34 0.34	2+0.34*1	2.34

Table 5 Starting point of manoeuvring at rudder angle 10°

Tablica 5. Početna točka manevriranja pri kutu kormila 10°

Degree of collision risk	Approach angle (°)	TD	Formula	Starting point of manoeuvring (Nm)
5	000 036/324	0.68 0.68	2+0.68*5	5.4
4	036/324 072/288	0.68 0.68	2+0.68*4	4.72
3	072/288 108/252	0.68 0.68	2+0.68*3	4.04
2	108/252 144/216	0.68 0.68	2+0.68*2	3.36
1	144/216 180	0.68 0.68	2+0.68*1	2.68

Results / *Rezultati*

We shall confine ourselves to the rudder angle 35° and 10°.

Collision Avoidance Manoeuvre at Rudder Angle 35° / *Manevar izbjegavanja sudara pri kutu od 35°*

APPROACH ANGLE 000°

The starting point of manoeuvre is at the distance 3,70 Nm. At own ship course alteration for 70° to starboard the observed target will be 2 Nm abeam of own ship in about 4 minutes. This course alteration however does not meet the CPA criterium of 1,3 Nm. Even with the increase of course alteration this criterium would not change essentially. Although the target would be at a safe distance, we simulated the manoeuvre at a greater distance (4,05 Nm), which is outside the given formula. The simulation confirmed that the target would be at a safe distance at course alteration 70°. As a matter of fact this course alteration is minimum. At course alteration 106º the approach would take place at major distance and would also meet the CPA condition, which is 2,0 Nm.

APROACH ANGLE 036°

The starting point of manoeuvre is at the distance 3,35 Nm. At own ship course alteration for 90° to starboard, the target observed will be 2,0 Nm abeam of own ship in about 3 minutes. The manoeuvre meets only our criterium, as the CPA is 1,6 Nm.

APROACH ANGLE 072°

The starting point of manoeuvre is at the distance 3,00 Nm. At own ship course alteration for 110° to starboard the target observed will be 2,0 Nm abeam of own ship in about 2 minutes. The manoeuvre meets only our criterium, as the CPA is 1,8 Nm.

APROACH ANGLE 108°

The starting point of manoeuvre is at the distance 2,70 Nm. At own ship course alteration for 75° to port (true course 284°) the target observed will be 2,0 Nm abeam of own ship in about 16 minutes. The manoeuvre meets both criteria. Turning to port was carried out due to the said Rule 15.

APROACH ANGLE 144°

The starting point of manoeuvre is at the distance 2,35 Nm. At own ship course alteration for 45° to port (true course 314°) the target observed will be 2,0 Nm abeam of own ship in about 10 minutes. The manoeuvre meets both criteria.

APROACH ANGLE 170°

Due to radar or ARPA limitations (loss of signal) the trial was carried out in the area of this sector. The starting point of manoeuvre is at the distance 2,35 Nm. At own ship course alteration for 20° to port (true course 340°) the target observed will be 2,0 Nm abeam of own ship in about 20 minutes. The manoeuvre meets only our criterium, as the CPA is 1,4 Nm. However, further increase of angle would meet also the other criterium.

APROACH ANGLE 190°

Due to above mentioned difficulties in the sector 1. starboard the trial in the sector 1. port was carried out also in the area of this sector. The starting point of manoeuvre is at the distance 2,35 Nm. At own ship course alteration for 26° to starboard the target observed will be 2,0 Nm abeam of own ship in about 20 minutes. The manoeuvre meets only our criterium, as the CPA is 1,4 Nm. However, further increase of angle would meet also the other criterium.

APROACH ANGLE 216°

The starting point of manoeuvre is at the distance 2,35 Nm. At own ship course alteration for 38° to starboard the target observed will be 2,0 Nm abeam of own ship in about 16 minutes. The manoeuvre meets both criteria.

APROACH ANGLE 252°

The starting point of manoeuvre is at the distance 2,65 Nm. At own ship course alteration for 79° to starboard the target observed will be 2,0 Nm abeam of own ship in about 12 minutes. The manoeuvre meets both criteria.

APROACH ANGLE 288º

The starting point of manoeuvre is at the distance 3,0 Nm. At own ship course alteration for 126° to starboard the target observed will be 2,0 Nm abeam of own ship in about 16 minutes. The manoeuvre meets only our criterium, as the CPA is 1,4 Nm. However, further increase of angle would meet also the other criterium.

APROACH ANGLE 324°

The starting point of manoeuvre is at the distance 3,35 Nm. At own ship course alteration for 69° to starboard the target observed will be 2 Nm abeam of own ship in about 3 minutes. But this course alteration does not meet the CPA criterium, as it is *"only"* 0,7 Nm. Even with further increase of course alteration this criterium would not change significantly (the difference is 0,5 Nm at course alteration for 179° to starboard). The manoeuvre meets both criteria only in case the manoeuvring starts at the upper limit, i.e. at the distance 3,70 Nm.

Collision Avoidance Manoeuvre at Rudder Angle 10° / ***Manevar izbjegavanja sudara pri kutu kormila od 10°***

APROACH ANGLE 000°

The starting point of manoeuvre is at the distance 5,40 Nm. At own ship course alteration for 53° to starboard the target observed will be 2 Nm abeam of own ship in about 8 minutes. But this course alteration does not meet the CPA criterium, as it is 1,7 Nm. However, with further increase of course alteration the manoeuvre would also meet the CPA criterium. Like with 35° rudder angle we tried to start manoeuvring at major distance (6,05 Nm). The manoeuvre meets both criteria at minor course alteration (46°).

APROACH ANGLE 036°

The starting point of manoeuvre is at the distance 4,70 Nm. At own ship course alteration for 72° to starboard the target observed will be 2,0 Nm abeam of own ship in about 7 minutes. The manoeuvre meets both criteria.

APROACH ANGLE 072°

The starting point of manoeuvre is at the distance 4,05 Nm. At own ship course alteration for 90° to starboard the target observed will be 2,0 Nm abeam of own ship in about 4 minutes. The manoeuvre meets both criteria.

APROACH ANGLE 108°

The starting point of manoeuvre is at the distance 3,35 Nm. At own ship course alteration for 69° to port (true course 291°) the target observed will be 2,0 Nm abeam of own ship in about 16 minutes. The manoeuvre meets both criteria.Turning to port was carried out due to the said Rule 15.

APROACH ANGLE 144°

The starting point of manoeuvre is at the distance 2,70 Nm. At own ship course alteration for 40° to port (true course 320°) the target observed will be 2,0 Nm abeam of own ship in about 10 minutes. The manoeuvre meets both criteria.Turning to port was carried out due to the said Rule 15.

APROACH ANGLE 170°

Due to radar or ARPA limitations (loss of signal) the trial was carried out in the area of this sector The starting point of manoeuvre is at the distance 2,70 Nm. At own ship course alteration for 20° to port (true course 340°) the target observed will be 2,0 Nm abeam of own ship in about 25 minutes. The manoeuvre meets only our criterium, as the CPA is 1,6 Nm. However, further increase of angle would meet also the other criterium.

APROACH ANGLE 190°

Due to above mentioned difficulties in the sector 1. starboard the trial was carried out also in the sector 1. in the area of this sector. The starting point of manoeuvre is at the distance 2,70 Nm At own ship course alteration for 20° to starboard the target observed will be 2,0 Nm abeam of own ship in about 25 minutes. The manoeuvre meets only our criterium, as the CPA is 1,5 Nm. However, further increase of angle would meet also the other criterium.

APROACH ANGLE 216°

The starting point of manoeuvre is at the distance 2,70 Nm. At own ship course alteration for 34° to starboard the target observed will be 2,0 Nm abeam of own ship in about 20 minutes. The manoeuvre meets both criteria.

APROACH ANGLE 252°

The starting point of manoeuvre is at the distance 3,35 Nm. At own ship course alteration for 71° to starboard the target observed will be 2,0 Nm abeam of own ship in about 20 minutes. The manoeuvre meets both criteria.

APROACH ANGLE 288°

The starting point of manoeuvre is at the distance 4,05 Nm. At own ship course alteration for 114° to starboard the target observed will be 2,0 Nm abeam of own ship in about 25 minutes. The manoeuvre meets both criteria.

APROACH ANGLE 324°

The starting point of manoeuvre is at the distance 4,70 Nm. At own ship course alteration for 51° to starboard the target observed will be 2,0 Nm abeam of own ship in about 5 minutes. But this course alteration does not meet the CPA criterium, as it is only 1,2 Nm. Even with major course alteration this criterium would not change significantly (the difference is 0,4 Nm at course alteration for 166° to starboard). The manoeuvre meets both criteria only in case the manoeuvring starts at the upper limit, i.e. at the distance 5,40 Nm.

CONCLUSION / ***Zaključak***

Throughout the research from conception to realisation we were facing problems and dilemmas. Now when the research is over, it seems that we are only at the beginning. The reasearch reveals new findings and proposes novelties, which would provide a higher degree of effectiveness in the choice of collision avoidance strategy. However, we should not expect radical decrease of collisions even with the proposed optimal model of collision avoidance manoeuvre, as the change of behaviour pattern of a navigating officer is a long term process which requires also the training of definite technical and technological conditions.

The effectiveness of the proposed model depends on technological and human factors, particularly the interrelations between the management and support levels. The navigating officer thus remains the key factor providing efficient execution of the proposed manoeuvre model.

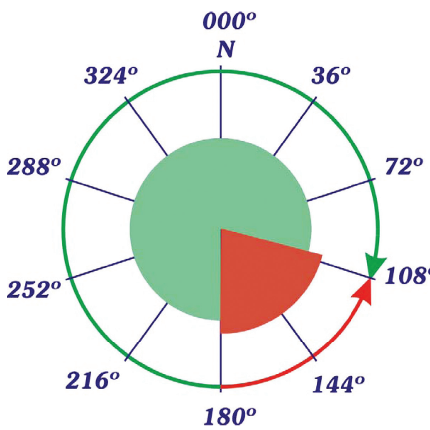

Figure 9 Schematic demonstration of the model of optimal collision avoidance manoeuvre on the high seas
Tablica 9. Shematski prikaz modela optimalnog manevra izbjegavanja sudara na otvorenom moru

The results of the research [4] confirm the hypotheses of the optimal avoidance and generally support its application of manoeuvring at lower limits of the sector. However, the above definite sectors (5th sector, above all approach angle 180°) require the application of the model at major distances or at the upper limits of each individual sector. The very 5th sector on the portside and the approach angle 180° in some trials proved the wrongly set algorithm of the model. The research findings also confirmed that the collision course decisively affects the reliability of general conclusions, as it directly depends on the relative speed of the target observed and on the fact that the algorithm of the manoeuvre can be developed by dividing the radar screen on sectors.

It should be pointed out that the results of the experimental part derive above all from the said research, therefore they can be related or transferred entirely to all circumstances. Particularly on the rough sea the safety distance should increase for at least 0,5 Nm according to Beaufort scale. Approach is considered to be at a safe distance when ships approach far enough to avoid collision, particularly in case of wrong manoeuvre or in some unpredicted circumstances, such as the main propulsion or steering gear failure.

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