

# Comparative Study of the Accuracy of AIS and ARPA Indications. Part 1. Accuracy of the CPA Indications

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**ABSTRACT:** According to the IMO recommendation when the target data from radar tracking and AIS are both available and the association criteria are fulfilled such that the radar and AIS information are considered as for one physical target, then as a default condition in radar equipment should be automatically selected and displayed the AIS target symbol and the alphanumerical AIS target data only. The article presents research conducted in real sea conditions on the reliability of information presented by the ship's AIS and ARPA about the passing distance with the other vessel tracked by radar equipment and fitted with AIS.

## 1 INTRODUCTION

According to the Resolution MSC.192(79) "Adoption of the revised performance standards for radar equipment" adopted by the International Maritime Organisation (IMO) on 6<sup>th</sup> of December 2004, in radar installed on sea going vessels on or after 1<sup>st</sup> of July 2008, if the target data from automatic identification system (AIS) and radar tracking are both available and the association criteria (position, motion, etc.) are fulfilled such that the AIS and radar information are considered as concerning one physical target, then as a default condition, the AIS target symbol and the alphanumerical AIS target data should be automatically selected and displayed [1].

But at the same time, according to the recommendations of the subsequent IMO Resolution A.1106(29) „Revised guidelines for the operational use of shipborne automatic identification systems (AIS)” adopted on 2<sup>nd</sup> of December 2015, the AIS may be recommended as an anti-collision device in due time and its introducing has not impact on the Rule 19 “Conduct of vessels in restricted visibility” of the

International Regulations for the Preventing Collision at Sea (COLREG) and its interpretation. The ship's master and watch keeping officers (OOW) should not rely on AIS as the sole information system, but should make use of all safety-relevant information available. In general, data received via AIS improves the quality of the information available to the OOW on board a ship. AIS is a useful source of supplementary information to that derived from navigational systems including radar. It may be used to assist in collision avoidance decision-making as an additional source of information which supports radar and radar tracking aids, by assisting in [2]:

- Identification of targets by name, call sign, ship type and an navigational status;
- Presentation of targets heading;
- Immediate identification of manoeuvres performed by targets; and
- More accurate presentation of the targets courses and speeds over ground and rate of turn.

It means, introducing of AIS on sea going vessels changes significantly possibility of maintaining a proper look-out and assessment of the meeting

situation with other vessel, particularly in restricted visibility.

Two basic parameters needed to assess the risk of collision in meeting situation between two vessels at sea are passing distance and passing time called respectively closest point of approach (CPA) and time to the closest point of approach (TCPA). IEC Standard 61993-2 presenting performance standards for AIS required that if AIS display equipment provides facilities for the calculation of CPA and TCPA then the facilities should comply with the relevant clauses of the IEC Standard 62388 "Shipborne radar – Performance requirements, methods of testing and required test results" [3]. This standard specifies the minimum operational and performance requirements conforming to performance standards not inferior to those adopted by IMO in the Resolution MSC.192(79) [4]. According to that standard, accuracy of radar tracking shall be as presented in Table 1 [1,4].

In maritime navigation are officially used as the units of distance and speed nautical miles (M) and knots (kn). ARPA and AIS present values of the distance, CPA and speed in these units and due to that, they are presented in this paper respectively in nautical miles and kilometres and in knots and m/s (1 M = 1852 m; 1 knot = 1 M/h  $\approx$  0.514 m/s).

Mentioned in Table 1 time of steady state means radar tracking a target, proceeding at steady motion [1,4]:

- after completion of the acquisition process; or
- without a manoeuvre of target or own ship; or
- without target swap or any disturbance.

There are available some publications comparing the accuracy of the position, course and speed presented by the AIS and radar tracking [5]. But it is still an open question the accuracy and reliability of information about CPA indicated by AIS as compared with the accuracy of its value calculated on the basis of radar tracking by automatic radar plotting aid (ARPA) and automatic tracking aid (ATA).

The measurements reported in this article were carried out to find the answer to this question.

## 2 DESCRIPTION OF THE MEASUREMENTS

The measurements were conducted in real (not simulated) conditions during the sea voyages of ships listed in Table 2 and presented in Figures 1, 2 and 3, using installed on these vessels AIS and radar equipment mentioned in this table too. JRC is the abbreviation of Japan Radio Company Ltd. Weather conditions during the tests describes the state of the sea, expressed in degrees of the Douglas scale in the last column of Table 3.

Tests were carried out during more than 100 meeting situations with other vessels. In this article, to calculate accuracy of the CPA indication were analysed only 55 meeting situations listed in Table 3 during which both ships (own and opposite) did not take any manoeuvres and were proceeding with steady courses and speeds.



Figure 1. Bulk carrier "Magdalena Oldendorff" [9]



Figure 2. LPG carrier "Pampero" [10]



Figure 3. Multipurpose vessel "ESL Africa" [11]

Table 1. Tracked target accuracy (95% probability figures) [1,4]

Time of steady state tracking [min]	Relative course [°]	Relative speed [kn / m/s]	CPA [M / km]	TCPA [min]	True course [°]	True speed [kn / m/s]
1 min: trend	11	1.5 / 0.8 or 10% (whichever is greater)	1.0 / 1.85	-	-	-
3 min: motion	3	0.8 / 0.4 or 1% (whichever is greater)	0.3 / 0.56	0.5	5	0.5 / 0.3 or 1% (whichever is greater)

Table 2. Ships on which tests were carried out [6,7,8]

Ship's name	Magdalena Odendorff	Pampero	ESL Africa
Ship's type	Bulk carrier	LPG tanker	Multipurpose vessel
Gross tonnage	106884	46789	11864
Length [m]	299.9 m	226.0 m	143.0 m
Service speed [kn / m/s]	15.6 / 8,0	16.7 / 8,6	13.2 / 6.8
Utilised radar and ARPA equipment / manufacturer	JMA-9132-SA, JMA-9122-9XA / JRC	JMA-9172-SA, JMA-9122-9XA /JRC	GR3017 (X-Band), GR3018 (S-Band), ARPA Multipilot 1100 / SAM Electronics GmbH
Utilised AIS / manufacturer	JHS-183 / JRC	JHS-183 / JRC	DEBEG 3400 / SAM Electronics GmbH

Table 3. Observed ships [6,7,8,12]

No	Ship's name	T	L [m]	Speed [kn/m/s]	Distance [M/km]	Sea state
1	Alexandra	CS	270	17.5 / 9.0	2.5-2.2 / 4.6-4.1	2
2	Belgian Express	C	180	13.0 / 6,7	1.0-0.7 / 1.9-1.3	4
3	Celtic Ambassador	CS	88	9.1 / 4.7	13.4-12.4 / 24.8-23.0	5
4	China Peace	B	289	0 / 0	16.8-14.5 / 31.1-26.9	3
5	Christopher	CS	171	15.1 / 7.8	1.8-1.6 / 3.3-3.0	5
6	Coral Meandra	T	91	11.1 / 5.7	1.5-1.4 / 2.8-2.6	4
7	Corcovado	CS	207	0.5 / 0.3	18.9-15.8 / 35.0-29.3	1
8	CSCL Jupiter	CS	366	18.2 / 9.4	3.6-2.6 / 6.7-4.8	3
9	F.D. Gennaro Aurilia	B	225	12.0 / 6.2	14.1-13.2 / 26.1-24.4	3
10	Flinter Aland	CS	132	10.7 / 5.5	7.9-7.1 / 14.6-13.1	4
11	Heinrich	T	114	11.9 / 6.1	18.6-18.1 / 34.4-33.5	2
12	Histria Ivory	T	179	10.8 / 5.6	17.1-17.0 / 31.7-31.5	6
13	Hyundai Unity	C	294	13.3 / 6.8	9.3 / 17.2	3
14	Lena River	T	290	0 / 0	6.7-3.4 / 12.4-6.3	2
15	Navin Kestrel	CS	116	10.2 / 5.3	5.2-4.4 / 9.6-8.1	3
16	Ocean Trader	CS	180	11.1 / 5.7	19.8-19.6 / 36.7-36.3	4
17	Pacific Heron	SP	88	4.8 / 2.5	9.0-7.8 / 16.7-14.4	1
18	Panther	CS	207	16.1 / 8.3	11.4-10.9 / 21.1-20.2	3
19	Regio Mar	FV	21	8.0 / 4.1	6.5-3.0 / 12.0-5.6	2
20	Suez Vasilis	T	274	14.0 / 7.2	2.0-1.8 / 3.7-3.3	4
21	Tian Zhu Feng	B	225	10.8 / 5.6	16.8-16.4 / 31.1-30.4	7
22	Union Ranger	CS	185	11.7 / 6.0	18.7-18.4 / 34.6-34.1	1
23	Varvara	CS	225	11.2 / 5.8	5.7-5.1 / 10.6-9.4	3
24	APL Vancouver	C	328	19.2 / 9.9	18.4-13.1 / 34.1-24.3	4
25	Ara Antwerpen	CS	145	11.2 / 5.8	9.2-3.0 / 17.0-5.6	4
26	Beatriz B	CS	159	12.9 / 6.6	19.0-12.9 / 35.2-24.0	6
27	Bomar Resolute	CS	232	15.4 / 7.9	7.0-1.8 / 13.0-3.3	1
28	Cosco Jingtangshan	B	177	10.0 / 5.1	13.1-6.6 / 24.3-12.2	5
29	Eken	T	135	12 / 6,2	4.7-2.0 / 8.7-3.7	2
30	Gas Pasha	CS	96	9.3 / 4.8	14.1-8.4 / 26.1-15.6	3
31	Hoegh Shanghai	CS	229	9.2 / 4.7	17.1-11.3 / 31.7-20.9	2
32	HSC	B	289	11.6 / 6.0	7.6-5.7 / 14.1-10.6	3
33	Jacamar Arrow	B	199	14.0 / 7.2	5.5-1.3 / 10.2-2.4	5
34	Maersk Cape Coast	C	249	15.0 / 7.7	6.5-2.6 / 12.0-4.8	1
35	NYK Altair	C	333	14.1 / 7.3	12.5 / 23.2	4
36	Port Shanghai	B	190	10.0 / 5.1	7.7-2.5 / 14.3-4.6	5
37	Rome Trader	CS	179	14.4 / 7.4	19.5-12.6 / 36.1-23.3	2
38	Rome Trader	CS	179	14.4 / 7.4	10.1-3.4 / 18.7-6.3	2
39	Thorco Legion	CS	132	12.35 / 6.4	13.5-6.8 / 25.0-12.6	3
40	Varamo	C	166	25.3 / 13.0	6.9-1.2 / 12.8-2.2	4
41	Abis Calais	CS	115	9.4 / 4.8	16-13.7 / 29.6-25.4	4
42	Arklow Cadet	CS	87	10.6 / 5.4	6.7-4.3 / 12.4-8.0	3
43	Bulk Switzerland	B	289	9.5 / 4.9	20.0-18.0 / 37.0-33.3	5
44	Cap San Marco	C	333	20.0 / 10.3	4.3-2.7 / 8.0-5.0	4
45	Carnival Valor	P	292	18.2 / 9.4	3.4-2.9 / 6.3-5.4	4
46	Coral Lophelia	T	109	13.4 / 6.9	17.1-16.3 / 31.7-30.2	5
47	Free Neptune	CS	185	11.5 / 5.9	14.2-11.5 / 26.2-21.3	2
48	Horncap	C	153	14.5 / 7.5	5.6-2.9 / 10.4-5.4	3
49	Ilyas Efendiyev	CS	140	8.4 / 4.3	9.6-4.9 / 17.8-9.1	2
50	JŚ Columbia	B	199	14.4 / 7.4	16.7-12.8 / 30.9-23.7	2
51	MSC Rachele	C	334	19.5 / 10.0	23.4-17.5 / 43.3-32.4	5
52	NCC Danah	T	183	13.5 / 6.9	5.6-3.3 / 10.4-6.1	7
53	OOCL Korea	C	366	15.8 / 8.1	5.7-1.6 / 10.6-3.0	7 sw
54	Rio de Janeiro Express	CS	260	13.4 / 7.4	19.5-15.4 / 36.1-28.5	2
55	Spirit of Britain	F	213	23.5 / 12.1	9.1-8.3 / 16.9-22.4	3

- The terms and abbreviations used in Table 3 mean:
- Name - name of the observed vessel;
  - T - type of the ship indicated by AIS:
    - B - bulk carrier;
    - C - container vessel;
    - CS - cargo ship;
    - F - ferry boat;
    - FV - fishing vessel;
    - P - passenger ship;
    - SP - special purpose ship; and
    - T - tanker;
  - L - the length of the vessel presented on the website;
  - Distance - distance to the observed ship during the measurement; and
  - Sea - sea state expressed in degrees of the Douglas scale, sw means swell.

In each test were recorded, simultaneously every 30 seconds, following parameters of the observed vessel indicated by ARPA and AIS: bearing, distance, true course, true speed, CPA and TCPA.

In all cases, observed ship was tracked by ARPA for at least 5 minutes before the start of registration and both vessels (own and opposite) did not take any manoeuvres at this time and later during the registration.

### 3 DISCUSSION OF TESTS RESULTS AND CONCLUSIONS

Described tests were conducted in order to check whether, when data from AIS and radar tracking are both available and the association criteria are fulfilled, the person in command and manoeuvring the ship (captain or watch keeping officer) can rely on CPA value of other vessel available from AIS only. The amount of the measurements is small and makes it impossible to determine any statistical relationships but allows to formulate some general observations.

There were observed by AIS and tracked by ARPA ships of different sizes, from the small fishing vessel to large container ships and tankers, proceeding with different speeds in different meeting situations and in different weather conditions, including stormy weather. They were passing own ship at different CPA, between, according to the data received from ARPA, 0.36 M (0.67 km) and 17.18 M (31.82 km). Results of conducted tests are presented in Table 4. Errors of the CPA indication greater than their limit value defined in the mentioned IEC standard and IMO resolution are printed in this Table in bold and underlined,  $\sigma$  - standard deviation.

Table 4. Tests results (95% probability figures)

No	CPA (ARPA)		CPA (AIS)	
	Mean value [M / km]	$2\sigma$ [M / km]	Mean value [M / km]	$2\sigma$ [M / km]
<b>Parallel courses - overtaking</b>				
1	2.11 / 3.91	0.16 / 0.30	2.07 / 3.83	0.18 / 0.33
2	0.69 / 1.28	0.04 / 0.07	0.67 / 1.24	0.04 / 0.07
3	2.29 / 4.24	<b>3.04 / 5.63</b>	2.15 / 3.98	<b>1.42 / 2.63</b>
4	4.50 / 8.33	<b>1.74 / 3.22</b>	4.38 / 8.11	<b>0.74 / 1.37</b>
5	1.54 / 2.85	0.24 / 0.44	1.44 / 2.67	<b>0.42 / 0.78</b>
6	1.17 / 2.17	0.20 / 0.37	1.21 / 2.24	0.20 / 0.37
7	2.70 / 5.00	<b>0.42 / 0.78</b>	2.65 / 4.91	<b>0.36 / 0.67</b>
8	1.62 / 3.00	<b>0.48 / 0.89</b>	1.56 / 2.89	<b>0.56 / 1.04</b>
9	6.72 / 12.45	<b>5.82 / 10.78</b>	7.66 / 14.19	<b>1.60 / 2.96</b>
10	2.65 / 4.91	<b>1.20 / 2.22</b>	2.83 / 5.24	<b>0.70 / 1.30</b>
11	11.31 / 20.95	<b>5.24 / 9.70</b>	11.17 / 20.69	<b>3.94 / 7.30</b>
12	15.71 / 29.09	<b>4.64 / 8.59</b>	15.27 / 28.28	<b>4.52 / 8.37</b>
13	9.25 / 17.13	0.06 / 0.11	9.18 / 17.00	0.06 / 0.11
14	0.68 / 1.26	0.02 / 0.04	0.69 / 1.28	0.04 / 0.07
15	2.39 / 4.43	<b>0.64 / 1.19</b>	2.41 / 4.46	0.28 / 0.52
16	17.18 / 31.82	<b>5.20 / 9.63</b>	15.71 / 29.09	<b>6.12 / 11.33</b>
17	6.81 / 12.61	0.22 / 0.41	6.79 / 2.58	0.16 / 0.30
18	4.70 / 8.70	<b>3.42 / 6.33</b>	4.68 / 8.67	<b>2.54 / 4.70</b>
19	2.65 / 4.91	0.14 / 0.26	2.58 / 4.78	0.12 / 0.22
20	1.64 / 3.04	0.18 / 0.33	1.45 / 2.69	0.16 / 0.30
21	11.31 / 20.95	<b>8.68 / 16.08</b>	9.99 / 18.50	<b>7.04 / 13.04</b>
22	8.47 / 15.69	<b>7.52 / 13.93</b>	9.21 / 17.06	<b>9.32 / 17.26</b>
23	0.47 / 0.87	<b>0.82 / 1.52</b>	0.32 / 0.59	<b>0.34 / 0.63</b>
<b>Reciprocal courses</b>				
24	9.76 / 18.08	<b>1.14 / 2.11</b>	9.81 / 18.17	0.20 / 0.37
25	1.22 / 2.26	0.18 / 0.33	1.17 / 2.17	0.16 / 0.30
26	3.38 / 6.26	<b>0.94 / 1.74</b>	3.35 / 6.20	0.26 / 0.48
27	1.64 / 3.04	<b>0.42 / 0.78</b>	1.64 / 3.04	0.12 / 0.22
28	3.34 / 6.19	<b>0.38 / 0.70</b>	2.95 / 5.46	0.22 / 0.41
29	0.36 / 0.67	0.06 / 0.11	0.36 / .67	0.04 / 0.07
30	1.45 / 2.69	0.22 / 0.41	1.54 / 2.85	0.16 / 0.30
31	1.83 / 3.39	<b>0.82 / 1.52</b>	1.98 / 3.67	0.28 / 0.52
32	5.55 / 10.28	0.12 / 0.22	5.48 / 10.15	0.08 / 0.15
33	1.11 / 2.06	0.04 / 0.07	1.11 / 2.06	0.08 / 0.15
34	2.13 / 3.94	0.10 / 0.19	2.05 / 3.80	0.08 / 0.15
35	11.13 / 20.61	<b>4.54 / 8.41</b>	6.13 / 11.35	<b>6.48 / 12.00</b>
36	2.38 / 4.41	0.04 / 0.07	2.19 / 4.06	0.18 / 0.33
37	1.36 / 2.52	<b>0.60 / 1.11</b>	1.36 / 2.52	<b>0.42 / 0.78</b>
38	1.36 / 2.52	<b>0.32 / 0.59</b>	1.37 / 2.54	0.10 / 0.19
39	2.27 / 4.20	<b>0.64 / 1.19</b>	2.39 / 4.43	0.12 / 0.22
40	1.15 / 2.13	0.04 / 0.07	1.28 / 2.37	0.16 / 0.30
<b>Crossing courses</b>				
41	4.43 / 8.20	<b>1.86 / 3.44</b>	4.33 / 8.02	<b>0.42 / 0.78</b>
42	3.72 / 6.89	0.14 / 0.26	3.71 / 6.87	0.14 / 0.26
43	17.18 / 31.82	<b>0.76 / 1.41</b>	17.19 / 31.84	<b>0.50 / 0.93</b>
44	2.60 / 4.82	0.04 / 0.07	2.54 / 4.70	0.10 / 0.19
45	2.90 / 5.37	0.02 / 0.04	2.79 / 5.17	0.04 / 0.07
46	13.12 / 24.30	<b>6.44 / 11.93</b>	14.30 / 26.48	<b>0.32 / 0.59</b>
47	9.43 / 17.46	<b>1.22 / 2.26</b>	9.48 / 17.56	0.16 / 0.30
48	2.84 / 5.26	0.04 / 0.07	2.70 / 5.00	0.12 / 0.22
49	2.44 / 4.52	<b>0.58 / 1.07</b>	2.41 / 4.46	0.20 / 0.37
50	5.92 / 10.96	<b>0.52 / 0.96</b>	5.30 / 9.82	<b>0.32 / 0.59</b>
51	3.85 / 7.13	<b>4.64 / 8.59</b>	3.65 / 6.76	0.30 / 0.56
52	2.97 / 5.50	0.26 / 0.48	2.92 / 5.41	0.22 / 0.41
53	1.51 / 2.80	0.12 / 0.22	1.47 / 2.72	0.16 / 0.30
54	0.76 / 1.41	<b>0.66 / 1.22</b>	0.77 / 1.43	<b>0.32 / 0.59</b>
55	8.28 / 15.33	0.06 / 0.11	8.25 / 15.28	0.06 / 0.11

Table 5 presents the numbers of meeting situations where the CPA indications by AIS and ARPA had errors greater than their allowable value specified in the standards. Measurements have shown that the problem with accurate determination of CPA values occurs mainly during overtaking. In this meeting situation both ARPA and AIS indicated CPA with an

error greater than acceptable in 14 cases for 23 tested (in 61% of meeting situation). In 12 meeting situations problems with accurate indication of CPA value had both ARPA and AIS. In other meeting situations, AIS showed more frequently CPA values with acceptable accuracy than ARPA. ARPA errors exceeded the limit value in more than half the meeting situations (in 9 out of 17 for ships on reciprocal courses and in 8 out of 15 for crossing courses). AIS errors exceeded the limit value in 2 out of 17 meeting situations for ships on reciprocal courses and in 5 out of 15 situations for crossing courses only.

Table 5. The number of meeting situations where CPA errors were greater than their allowable value (for 95% probability figures)

Type of meeting situation	Number of meeting situations		
	Total	With CPA error greater than acceptable ARPA	AIS
Parallel courses - overtaking	23	14	14
Reciprocal courses	17	9	2
Crossing courses	15	8	5
Total	55	31	21

No clear correlation was found between the magnitude of the CPA errors and the state of the sea. The CPA indications in AIS and ARPA exceeded the allowable values for all sea states from 1 to 7 degrees in the Douglas scale.

The number of described in this paper measurements carried out on ships during their sea voyages is too small to formulate on their basis general conclusions about the accuracy of the CPA indications by ARPA and AIS, but they allow for the following initial conclusions:

- 1 On board AIS, like radar tracking aids (ARPA and ATA), may display the CPA value of the opposite vessel unstable and inaccurate in all states of sea.
- 2 Due to the possible instabilities and inaccuracies mentioned in the first conclusion, a systematic observation of the CPA value of opposite vessel indicated by both AIS and ARPA (ATA) should be recommended.

- 3 Attention of the AIS and ARPA manufacturers should be paid on the problem identified in the first conclusion.

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