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The AIS-Assisted Collision Avoidance

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Shipborne AIS provides independent traffic information to the bridge lookout on duty. This study examines the effect of AIS enhanced bridge lookout operation by means of a ship simulator. The two groups of participants, all qualified British deep sea deck officers, undertook identical simulation scenarios, but one group had the AIS on and the other did not. Significant differences were found between the two groups in reading the targets' privileged status and handling the head-on situation. Those with AIS information were found to avoid possible collisions faster than the group for whom AIS information was not available.

KEY WORDS

1. AIS. 2. Radar. 3. Collision Avoidance. 4. Simulation.

1. INTRODUCTION. The aim of a shipborne Automatic Identification System (AIS) is to help identify vessels, assist in target tracking, simplify information exchange and provide additional information to assist with situation awareness (IMO 2002). IMO Resolution A917 (22), describes AIS as a potential aid in collision avoidance and also highlights the use of AIS as an additional navigation system that supports (but does not replace) the existing navigational system.

AIS provides an independent platform of traffic information that is able to enhance and support ship's radar in collision avoidance manoeuvring. Depending upon the system's specifications, near real-time Rate of Turn (ROT) and engine-speed may also be available, while voyage information and navigational status can be obtained via the AIS network.

The consensus among users is that AIS has not reached system maturity in terms of the degree of system integration and data display. This study aims to examine the effect on end users operating AIS on the bridge. To examine the effect, a simulator experiment was undertaken, based on a merged AIS bridge operation with correct information displayed throughout the exercise. The focus was on the function of AIS in providing additional information to bridge operations during ship manoeuvring, with the effects of operating AIS measured by means of variable analysis.

2. METHODS.

2.1. *Scenario construction.* To test the effectiveness of AIS on bridge lookout operations, an independent variable was adopted by separating participants into two groups: Group A was able to obtain AIS information while on the bridge; Group B was not. The differing designs of the four simulation trials were classified by the collision avoidance geometries and actions taken by the target vessels. In terms of collision avoidance geometries, the four scenarios covered head-on, crossing and overtaking situations at the initial time of meeting. In regard to the actions taken by the target vessels, some target vessels gave way to the participant's own ship (OS), while others did not take any action despite a developing small Closest Point of Approach (CPA). With their access to AIS functions, participants in Group A were able to obtain further details about the surrounding sea traffic, including ROT information, engine-change information, voyage data and navigational status.

2.2. *The Simulator.* The simulator used in the research was a TRANSAS Navi-Trainer Professional 4000 (Version 4.51). Apart from the simulator's AIS Minimum Keyboard & Display (MKD), AIS data is merged with the bridge's radar and Electronic Chart Display and Information System (ECDIS). The arc of visibility from the wheelhouse was 135 degrees ahead, and views were also adjustable to see the rest of the scene.

2.3. *Limitations of this Experiment.* Due to the small number of qualified mariners who came forward to participate, there were some constraints on the simulator trials. Firstly, the trials were unable to utilise different ranges of visibility. A 3 nm restricted visibility was the only visibility situation simulated throughout the trials (see Section 2.4). Secondly, the effectiveness of AIS operation with AIS enhanced radar and ECDIS available was out of the scope of this research. Thus, group A participants were free to obtain AIS information from RADAR, ECDIS and the MKD.

Notwithstanding the criticism of AIS information maintenance in the real world (Harati-Mokhtari, Wall et al. 2007), the information transmitted via AIS was set/assumed to be entirely genuine and ready to be used by the participants. For instance, a non-SOLAS fishing boat could still send its vessel name, navigational status, etc. to the AIS network in the simulator exercises.

The simulated scenario was mainly interested in ship handling with traffic. Participants were allowed to control both engine and rudder, although tugs and thrusters were not considered in the scenarios. In order to reduce the number of variables being measured in regard to participants' behaviour in collision avoidance manoeuvring, the wind and current were limited and only visibility and wave conditions were considered in the simulator scenarios.

2.4. *Reduced visibility.* The advantage of radar is its utility during periods of reduced visibility (Valentine 1985) as it ensures earlier detection of oncoming traffic before the target comes in sight. As a result, the visibility setup became an important element in the construction of simulator scenarios. An escape action should be taken by the participant's ship if a target ship is 3 nm or less from them (Calvert 1960; Calvert 1961; Cockcroft 1972). Cockcroft further stated that collision avoidance action taken under 4 nm would be seen as a Close Quarter Situation (CQS); 3 nm was therefore set as the visibility range for all simulator scenarios.

2.5. *Bridge control.* The selected ship category was a 32,000 grt, 250 metre long container ship. The autopilot was active as a default mode for rudder control. A change of course could be made by ordering a new course on the autopilot or by switching to manual control. As the four scenarios were set in open sea, the speed was set as full sea speed. Although the engine was not at immediate readiness in the open sea situation, five-minutes notice could be given to the engine room to request engine stand-by if the participants decided this was necessary. From the authors' experiences, a modern ship's bridge may not need to give any notice to the engine room, while an older ship may need up to 30 minutes notice for engine standby. Considering the average time for each exercise, 5-minutes notice to the engine room was required.

2.6. *Data collection.* The data was collected by the track presentation from each of the participants. To study the moments of execution (Ishioka, Nakamura et al. 1996), the range at which action was taken (or the Time to Closest Point of Approach (TCPA) at which action was taken) was recorded. The distance off the given track on ECDIS was also recorded. To complete this mission, every participant was asked to turn back to the intended track when the collision risk had been cleared. Further comments and remarks from the bridge log were also collected for further discussion. The data collected from the simulator scenarios were categorised as:

- TCPA from the encountered vessel at which action was taken;
- Off-track distance;
- Collision avoidance manoeuvres.

2.7. *Data analysis.* The data collected from the simulator was analysed by means of descriptive methods and non-parametric tests, with particular attention being paid to the time of action (TCPA) and off-track distances. There were four pairs of simulator exercises undertaken by the two groups of mariners (Group A: AIS ON and Group B: AIS OFF). For a two-condition, unrelated design when different participants are used for each of the conditions, the Mann Whitney (MW) test should be used (Greene and D'Oliveira 1982). As a non-parametric test, MW is criticised as being less powerful than a parametric test, e.g. t-test (Dytham 2003). Nevertheless, non-parametric tests are less likely to find a significant result when there is no real difference. The reason is to reduce the probability of having a Type I error (see Table 1). To test the additional information from AIS, the hypotheses for testing the TCPA and off-track distance by MW were:

H_0: The two populations are identical with added AIS information.
H_a: The two populations are not identical with added AIS information.

By ranking the simulator results (action time and off-track distance), the MW tests calculate a U value (Table 2) to indicate the relationship between Group A and Group B. The smaller the U value, the larger the difference between the two compared groups. The critical value of U was set as 0·05. Significances ($P < 0{\cdot}05$) would be defined by rejecting the null hypothesis (H_0), showing that there is a significant difference arising from the independent variable (AIS availability).

3. EXPERIMENTAL PROCEDURES.

3.1. *Simulated scenarios.* The four pairs of exercises/tracks (Table 3) were named Exercises A&B, C&D, E&F, and I&J. The six participants from Group A undertook

Table 1. Errors and correct conclusions in hypothesis testing (Anderson, Sweeney et al. 1999).

Conclusion \ Population Condition	H_0 True	H_a True
Accept H_0	Correct conclusion	Type II error
Reject H_0	**Type I error**	Correct conclusion
Notes	The form for Null and Alternative Hypotheses $\begin{cases} H_0: \mu1 = \mu2 \\ H_a: \mu1 \neq \mu2 \end{cases}$	
Key	H_0: Null Hypotheses H_a: Alternative Hypotheses $\mu1$: median from a compared group $\mu2$: median from another compared group	

Table 2. U value, MW tests (Greene and D'Oliveira 1982).

$$U = n1n2 + \frac{nx(nx+1)}{2} - Tx$$

Key

n1: number of participants in Group A
n2: number of participants in Group B
Tx: largest rank total
nx: number of subjects in the group with the largest rank total

Table 3. Exercise description.

Group A	Group B	Exercise description	Vessels' codes and types
Ex A	Ex B	A head-on meeting with a fishing boat	OS: container ship TG1: container ship TG2: passenger ship TG3: fishing boat
Ex C	Ex D	A cross meeting with a privileged ship	OS: container ship TG1: container ship TG2: container ship TG3: bulk carrier TG4: container ship
Ex E	Ex F	A cross meeting with a vessel that is initially more than 22·5 degrees abaft own ship's beam	OS: container ship TG1: container ship TG2: bulk carrier TG3: container ship TG4: trawler TG5: trawler TG6: trawler
Ex I	Ex J	A cross meeting with a fast approaching vessel	OS: container ship TG1: high speed craft TG2: container ship TG3: trawler TG4: trawler
Key	Group A (sample n=6): AIS ON; Group B (sample n=7): AIS OFF; OS stands for own ship; TG stands for target vessel		

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Exercises A, C, E and I. The seven participants from Group B undertook Exercises B, D, F and J.

3.2. *Briefing*. A thorough briefing is essential prior to any simulator exercise (Valentine 1985). The procedure of a warm-up and four exercise sessions was laid out and the participants were then asked to follow a given track (a voyage plan), which was displayed on ECDIS. If any manoeuvre was made, the participants had to return to the given track after the collision risk was cleared (see Section 2.6).

3.3. *Familiarisation*. To minimise the positive and negative influences upon each participant's performance of using the simulator, some level of familiarity with the testing platform, i.e. the simulator, is required (National Research Council (US) 1996). After the briefing, an introduction was carried out consisting of simulator exercises followed by a warm-up practice. The purpose of the familiarisation session is to prevent possible bias occurring from unfamiliar use of the bridge controls during the trials. Redfern (1993) indicated that visual scene, ship handling, use of radar radio and other equipment should be described for familiarisation.

3.4. *Simulation disciplines*. Disciplines set up for the participants were:

- Standing Orders. Engines will not be available unless 5-minute notice is given to the engine room. A planned track for the participant's own ship will be displayed on the ECDIS. An exercise will be deemed finished when their ship is heading back to the planned track in the event that participants altered course during the exercises.
- AIS information is only available to Group A, where participants will have time to read all the important information from the AIS displays (RADAR, ECDIS and MKD) before the session starts.
- The reason for not having each participant try both paired exercises with and without AIS was to avoid bias that might occur by recalling the same scenario in the simulator experiment.
- The participants were divided into two groups using their rank to create as even a balance as possible. For instance, the two participants with the rank of masters were put into different groups. Next, each participant from both groups undertook the four exercises in a random order.

4. RESULTS.

4.1. *Target ship on reciprocal course*. Exercise A/B puts the participant's ship's track (code: OS) with a target vessel (code: TG3) in a head-on situation if the two vessels meet in visual range before altering courses (Figure 1). The OS and TG3 would have a TCPA after 18·55 minutes (CPA 0·1 nm) if the OS did not take any action (speed change and course alteration).

TG3 was set up as a comparatively smaller target at a range of 9 nm from the start of the exercise. Difficulties in detecting vessels were emphasised in this exercise. Due to the AIS assistance, information about the TG3 was clearly shown on all three AIS merged displays at the beginning. TG3 was displayed as a fishing boat under way using engine power and travelling at 11 knots on a reciprocal course with the OS. As the visibility was only 3 nm, TG3 was not visible until 12·6 minutes after the exercise started. The CPA/TCPA would be <1 nm/5·96 minutes if no action was taken onboard OS.

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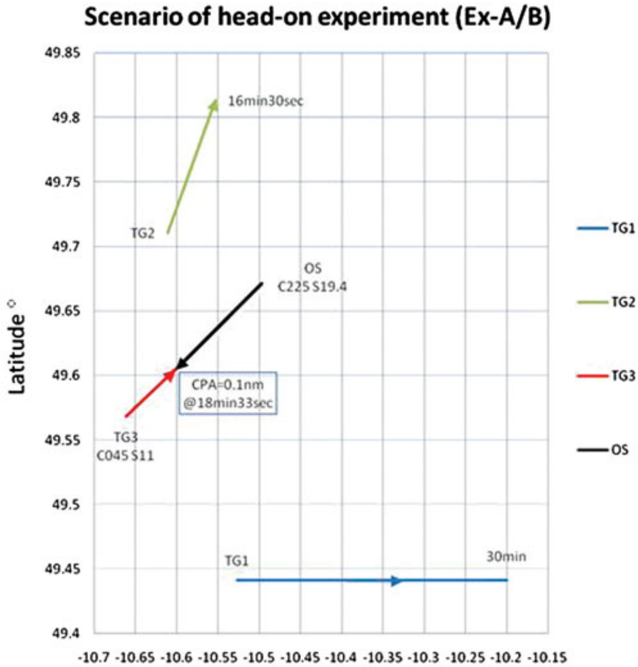

Figure 1. Original tracks for Exercise A/B.

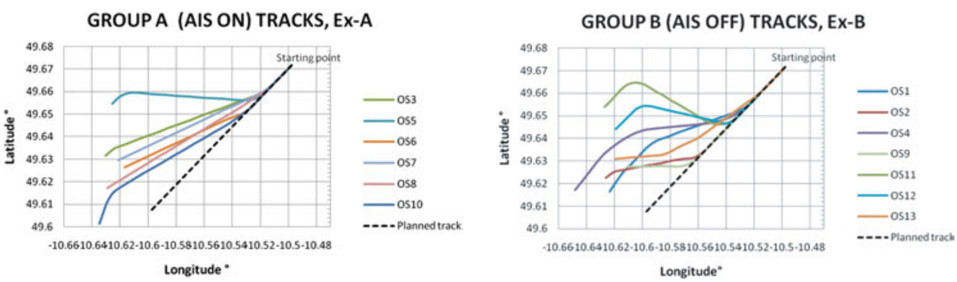

Figure 2. All ship tracks from Ex-A (left) and Ex-B (right).

In this exercise, all participants decided to take action before the oncoming TG3 was in visual contact, thus relying on electronic equipment. According to COLREGs, Rule 19 suggests not altering course to port if the approaching vessel is forward of its beam (except in an overtaking situation). While TG3 kept a steady speed and reciprocal course relative to the OS, all actions taken by the participants were to alter course to starboard. In Figure 2 the participants' exercises are displayed for Groups A and B respectively.

Regarding the action taken by the participants, the average TCPA from the TG3 at which action was taken was 12·96 minutes (Standard Deviation (s):2·68 min.). On average, Group A took action at TCPA: 14·60 minutes (s: 1·15 min.) from TG3,

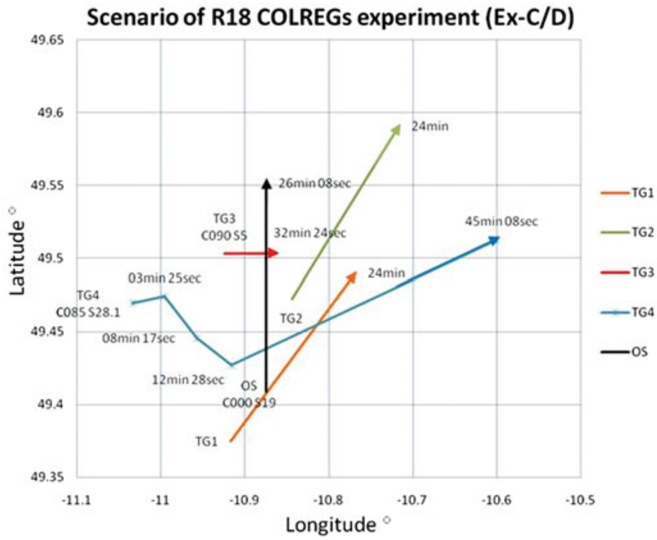

Figure 3. Original tracks for Exercise C/D.

while Group B did it at an average TCPA: 11·55 minutes (*s*: 2·89 min.). Overall, Group A took action earlier, by an average 3·05 minutes of the TCPA, than Group B did.

An alteration of course back to the planned track indicates that a threat of collision from the TG3 no longer existed. The average distance off the planned track by all the participants was 1·72 nm (*s*: 0·55 nm). Group A took 1·69 nm (*s*: 0·60 nm) off the planned track before heading back, whereas Group B took 1·75 nm off (*s*: 0·56 nm) the track. In comparison, the own ships' tracks from Group B are shown in Figure 2 to be more scattered than Group A's own tracks. Two participants in Group B took action comparatively late, with one not taking any action until the OS was in a CQS (action taken when the TG3 was less than 4 nm from the OS). One participant expressed surprise at encountering the TG3. All participants in Group A accomplished the mission before a CQS developed. In addition, five of the six Group A participants passed the target outside the CPA distance (>1 nm).

4.2. *Meeting with a privileged vessel.* Exercise C/D puts the participant's own ship (code: OS) on a crossing situation with two targets (codes: TG4 and TG3), with both CPAs being less than 2 cables away in 13·72 minutes and 17·3 minutes respectively (Figure 3). The TG4 altered course (60° starboard) three minutes from the start of the exercise. It became clear that TG4 took action in order to avoid CQS with the OS. Thus, TG3 is of a greater concern.

TG3, initially two points off the own ship's port bow, was actually stricken by engine failure. A corresponding Not Under Command (NUC) signal was displayed both by two round-shaped balls and via the AIS data transmission. As it is more difficult to spot 0·6 metre round-shaped balls from a distance, participants in Group B (AIS OFF) would be unaware of the real situation of TG3 before visual contact.

COLREGs Rule 18, Responsibilities between vessels, says that a power-driven vessel should give way to any vessel that is suffering engine failure, rudder failure, etc. Although Rule 18 is not applicable in restricted visibility (Section III, COLREGs),

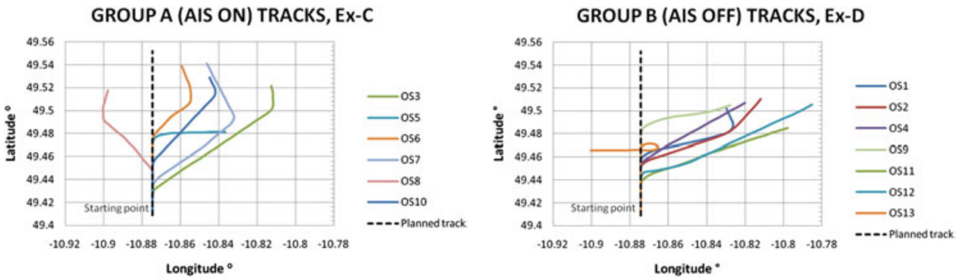

Figure 4. All ship tracks from Exercise C (left) and Exercise D (right).

AIS information can nevertheless still show a vessel's navigational status so that an early awareness of vessels with concerns about manoeuvrability can be achieved. Figure 4 shows that five of the six Group A participants altered course to starboard in response to the TG3 (OS 8 altered course to port) and all Group B participants altered course to starboard (OS 13 made a round turn).

The average TCPA from the TG3 at which action was taken was 10·38 minutes (*s*: 2·51 min.). With a fraction of difference, Group A took action at 10·81 minutes (*s*: 2·45 min.) from TG3, while Group B did it at an average 10·01minutes (*s*: 2·69 min.). An alteration of course back to the planned track indicates that the threat of collision from the TG3 no longer existed. The average off-track distance was 1·99 nm (*s*: 0·81 nm). Group A went 1·51 nm (*s*: 0·61 nm) off the planned track before heading back, while Group B went 2·39 nm (*s*: 0·76 nm) off the course.

4.3. *Overtaking and course alteration.* Exercise E/F had one of the targets (code: TG3) altering course toward the participant's own ship (code: OS). The initial configuration is given in Figure 5, where the OS has TG3 at a relative bearing of 115°, 6 nm distance. At one point (11 m 20 s from the start), TG3 altered course to port in response to a group of fishing boats on her bow and intended to cross ahead of the OS. After the steady course achieved by TG3, CPA/TCPA was reduced to 0·264 nm/11·65 min. At the time, TG3 was 5 nm at 3 points to starboard of OS.

Figure 6 shows that four Group A participants gave notice to the engine room and reduced speed after the TG3 altered course to port, while the other participants altered course to starboard (OS 3 made a round turn). In Group B, three participants altered course to starboard, two to port (with engine slowed down), one made a round turn to port and one slowed the engine.

The average TCPA at which action was taken was 8·77 minutes (*s*: 2·60 min.) from the TG3. On average, Group A took action at TCPA: 9·83 minutes (*s*: 2·44 min.) from TG3, while Group B did it at an average TCPA: 7·87 minutes (*s*: 2·55 min.). As a result, Group A took earlier action than Group B by a margin of 1·96 minutes of the TCPA. An alteration of course back to the planned track indicates that the threat of collision from the TG3 no longer exists. The average off-track distance was 0·41 nm (*s*: 0·44 nm). On average, Group A went 0·27 nm (*s*: 0·48 nm) off the planned track before heading back, while Group B went 0·54 nm (*s*: 0·39 nm) off the course.

The majority (7 out of 13) indicated that visibility was the main concern meaning that Rule 19 should apply. Two participants pointed out that the distance to the TG3 at the beginning (6 nm) meant that it would not be considered as an overtaking ship. These opinions were confirmed by Cockcroft. In contrast, three participants

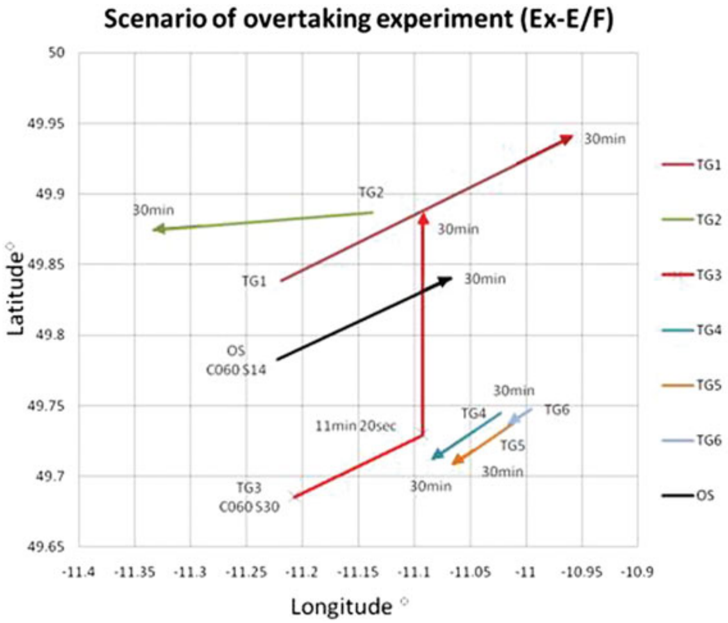

Figure 5. Original tracks for Exercise E/F.

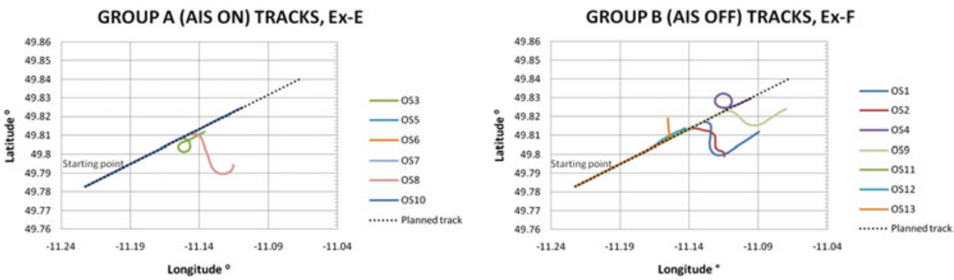

Figure 6. All ship tracks from Exercise E (Left) and Exercise F (right).

stated that it would have been an overtaking situation if the TG3 was in visual contact at the beginning. Although Group A took action in response to the oncoming TG3 a little earlier than Group B, there was little evidence to suggest that participants with ROT information from AIS acted differently to the other group (AIS off).

4.4. *Detection of speed change*. In Exercise I/J, the target ship (code: TG1) encountered was going to slow down. The participants from Group A were able to obtain TG1 identity as a High Speed Craft (HSC), heading north west, with near real-time dynamic information. The Ex-I/J original track (Figure 7) has TG1 slowing down her speed in order to keep clear of the participant's own ship (code: OS).

Among the AIS dynamic information, a speed change can be seen – which could give confirmed information to the Officers of the Watch (OOWs) relating to an opponent's intentions. In the initial configuration, the TG1 and OS would be in a crossing situation if both ships had each other in visual contact. Initially at 32 knots,

Table 4. Observation of TG1.

Time \ TG1	Displayed speed	CPA (nm)	TCPA	Distance (nm)
00min00sec	32kts steady	—	—	12·14
05min30sec	<32kts	0·05	09min16sec	7·45
08min07sec	<28kts	0·18	08min00sec	5·7
09min59sec	<22kts	0·43	07min25sec	4·5
13min15sec	<13kts	0·78	05min28sec	2·8

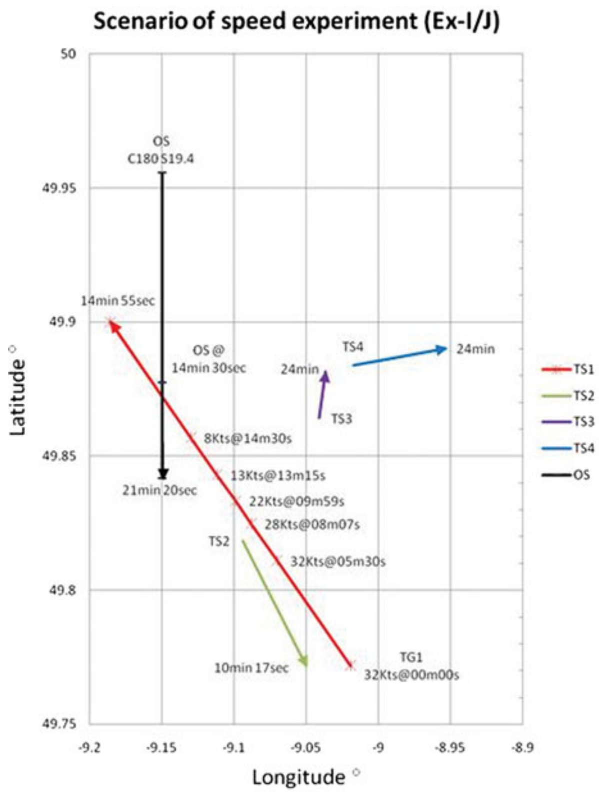

Figure 7. Original tracks for Exercise I/J.

TG1 was three points off the port bow of the OS at a range of 12·14 nm. Table 4 shows the observed speed, CPA/TCPA and distance of TG1 via the AIS displays. The CPA increased once the TG1 had reached 8 knots in 14 min 30 sec.

Twelve of the thirteen participants altered course to starboard in this exercise. In Rule 19, COLREGs, two vessels in a potential encounter shall act together (Lewison 1978; IMO 2003). Group A and Group B decided to take action (except OS10) when the oncoming TG1 was not yet in visual range. More information was fed to the participants from Group A, where TG1's ship type (HSC), dynamic information and destination were all available on the bridge. In order to stay clear of the OS, the

Table 5. Average action time and MW test results.

Descriptive & Statistical results	Exercises	**Ex-A/B**	Ex-C/D	Ex-E/F	Ex-I/J
Average TCPA Results	Group A (min.)	**14·59**	10·81	9·83	10·33
	Group B (min.)	**11·55**	10·01	7·87	9·18
	Subtraction (min.)	**3·04**	0·8	1·96	1·15
	$\left\lvert\frac{A-B}{B}\right\rvert$	**26·32%**	7·99%	24·90%	12·53%
Statistical Results	Group A Median (min.)	**15·03**	10·17	10·59	10·37
	Group B Median (min.)	**12·05**	10·33	7·93	9·63
	Mann Whitney U	**6·000**	20·000	12·000	12·000
	p-value (5%)	**0·032**	0·886	0·199	0·372
Key	U: a statistic reflects the smaller total of ranks; Bold results are tested significantly; Degree of freedom is 1 for the 4 pairs of exercises.				

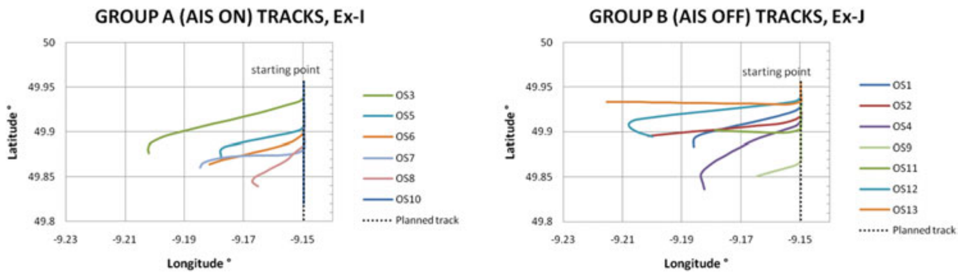

Figure 8. All ship tracks from Exercise I (left) and Exercise J (right).

TG1 eventually slowed her speed from 32 knots to 8 knots. Figure 8 shows the participants' exercises for the two groups.

The average TCPA at which action was taken was 9·66 minutes (*s*: 2·55 min.) from TG1. Group A took action at TCPA: 10·33 minutes (*s*: 2·17 min.), while Group B did it at an average 9·18 minutes (*s*: 2·86 min.). Group A took earlier action than Group B – by 1·15 minutes of the TCPA. An alteration of course back to the planned track indicates that the threat of collision from the TG1 no longer exists. The average off-track distance was 1·45 nm (*s*: 0·75 nm). Group A went 1·15 nm (*s*: 0·74 nm) off the planned track, while Group B went 1·71 nm (*s*: 0·71 nm). In terms of off-track distance, Group A spent less distance (by 0·56 nm) off the original course when considering the collision threat coming from TG1.

5. EVALUATION AND ASSESSMENT.

The evaluation and assessment cross-checked the time of collision avoidance action, the off-track distance taken and the collision avoidance behaviour.

5.1. *Action time evaluation.* Table 5 notes the considerable difference in the time action was taken in Exercises A/B and E/F. Group A took action 20% more quickly

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Table 6. Average off-track distances and MW test results.

Descriptive & Statistical results	Exercises	Ex-A/B	**Ex-C/D**	Ex-E/F	Ex-I/J
Average off-track distance results	Group A (nm)	1·69231	**1·51042**	0·26667	1·145455
	Group B (nm)	1·74725	**2·39286**	0·54142	1·709091
	Subtraction (nm)	−0·05494	**−0·88244**	−0·27475	−0·56364
	$\left\|\frac{A-B}{B}\right\|$	3·14%	**36·87%**	50·74%	32·98%
Statistical results	Median (Group A)	1·50 nm	**1·45 nm**	0·03 nm	1·25 nm
	Median (Group B)	1·66 nm	**2·19 nm**	0·51 nm	1·53 nm
	Mann Whitney U	18·500	**7·000**	11·500	12·000
	p-value (5%)	0·72024	**0·04520**	0·16876	0·19606
Key	U: a statistic reflects the smaller total of ranks; Bold results are tested significantly; Degree of freedom is 1 for the 4 pairs of exercises.				

than Group B. The control variable, AIS information, did have an impact on the action time of the participants, especially in the head-on and the overtaking scenarios. The use of a non-parametric test in paired populations is intended to assess the significance of the impact of the controlled variable. The controlled variable in this experiment was the availability of AIS information.

In Exercise A/B, the Group B participants only had a returned echo that, through a calculation from ARPA, showed a target vessel with a reciprocal course to the OS. Not only was there a 26·32% time difference in TCPA/action time, but a significant difference was also found in Exercise A/B (head-on situation). The null hypothesis (H_0) was then rejected. The two populations (AIS on and AIS off groups) were not identical in terms of the TCPA at which action was taken. The results mean that in the head-on situation Group A participants (Median = 15·03 minutes; AIS available) were significantly quicker in taking anti-collision action than Group B participants (Median = 12·05 minutes; AIS not available), MW U = 6·000, $p < 0{\cdot}05$.

5.2. *Off-track distance*. According to the standing order (see Section 3.4) on the simulator bridge, the participants have to alter course back to the planned track after the risk of collision is cleared. The off-track distances for the four pairs of exercises are shown in Table 6. Considerable differences in off-track distance were found in Exercises C/D, E/F and I/J. A difference of over 30% was also measured between the two groups.

In Exercise C/D (crossing a privileged ship), Group A participants were informed that the target ship (TG3) encountered was a NUC cargo ship. After the course alteration in response to the TG3, Group A participants decided to head back to the planned track much quicker than those in Group B. The null hypothesis (H_0) (see Section 2·7) – that the two populations (AIS on and AIS off) with a control on the given AIS information would be identical in their off-track distance performance – was then rejected. Group B (Median = 2·19 nm; AIS off) travelled a significantly wider off-track distance than Group A (Median = 1·45 nm; AIS on), with MW U = 7·000 and $P < 0{\cdot}05$. On average, almost 9 cables difference (36·87%) was measured

Table 7. Action taken before 'in sight'.

Vessel 2 \ Vessel 1	Action taken	Action not taken
Action taken	R19 applied	Risk may exist
Action not taken	Risk may exist	CQS

between the two groups. According to the MW test, Group A participants were significantly quicker than Group B participants in tackling the approaching threat in crossing a privileged ship (Ex-C/D; R18 meeting).

5.3. *Collision avoidance behaviour*. The participants took action in the simulation trials before the vessel concerned came 'In sight'. Rule 19 of COLREGs was commonly considered in this; this rule advises not altering course to port if the encountered target is forward of the ship's beam. All four scenarios involved encountering target vessels when the developing collision risks with the own ship were ahead of the own ship's beam.

In meeting with a head-on fishing boat (Exercise A/B), both groups of participants altered course to starboard. In Exercise C/D (R18 meeting), one Group A (AIS ON) participant decided to alter course to port after an acknowledgment of the privileged vessel (see Section 4.2). A concern was also raised by the presence of developing traffic on his starboard side. In Exercise E/F (overtaking scenario), none of the Group A participants altered course to port, whereas two out of seven Group B participants did. In Exercise I/J (speed meeting), not a single member of the two groups altered course to port.

Generally, there were greater differences in collision avoidance manoeuvring in Group B (in TCPA and off-track distance). However, Rule 19 was not intended to prevent OOWs altering course to port when a potential target is ahead of beam. The situation regarding emergency and traffic patterns might also influence an OOW's decision (see Rule 2 (b), COLREGs).

The actions taken by the participants in the four pairs of exercises showed little confusion about compliance with COLREGs. Hence, the *potential encounter* situation, where two ships would pass within half a mile of each other in the absence of avoiding action (Lewison 1978), was generally achieved. Finally, the *actual encounter* situation, where two ships eventually pass within half a mile of each other, was well avoided. According to Rule 19 COLREGs, action should be taken before being in sight by two vessels in a potential encounter situation. The Rule emphasises that CQS can be avoided by action taken by two meeting vessels when not in sight (Table 7). Overall, Group A with AIS information needed less time to acknowledge and handle the threat. Recognition that the vessel encountered was taking action and knowing its identity was found useful in situation awareness for collision avoidance.

6. DISCUSSION. The simulations gave an insight into how OOWs behave when additional AIS-provided information is available on the bridge. The research measurements used the TCPA at which action was taken and off-track distance to evaluate the impact of AIS assisted radar operation. The effect of adding AIS into the current bridge lookout operation was measured, and the conclusion was

reached that AIS-assisted collision avoidance does have an impact on the ship manoeuvring operation.

On the whole, Group A (AIS ON) took action quicker than Group B (AIS OFF) when considering the encountered target ship, with a distinctive difference of over 20% TCPA time in two of the four simulated scenarios. In terms of the time spent on collision avoidance manoeuvring (i.e. off-track distance), Group A (AIS ON) spent less time before heading back to the planned track, with a difference of over 30% in three of the four simulated scenarios. Significant differences were only found in Exercise A/B (Head-on meeting) in terms of action time (TCPA) and in Exercise C/D (R18 meeting) in terms of off-track distance. The hypothesis regarding AIS data was therefore rejected by the only controlling variable, AIS information. The effect of detecting a comparatively small target boat with AIS enabled the participants with AIS to act more quickly than the other group with no AIS. The effects of obtaining NUC signal via AIS allowed Group A (AIS ON) to complete the anti-collision manoeuvring more quickly and more efficiently.

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