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The Use of Simulators for the Emergency Response Training of Dynamic Positioning Operators of Class A Vessels

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ABSTRACT: The Dynamic Positioning System is classified into three types: DP class A, B, and C. DP class A vessels hold an overwhelming market share, but it lacks redundancy and is prone to failures. Therefore, in case of failure, there is a possibility of loss in positioning. Herein, we postulated that training Dynamic Positioning Operators (DPOs) for emergencies should mitigate maritime incidents. Accordingly, simulators have been proposed for achieving this objective. Using an experiential approach, nine DPOs were exposed to DPS simulation emergency response training at a lab in Japan. Each participant was given four tasks and a checklist to assist in decision-making to avoid collisions in various scenarios involving marine structures. An analysis of the simulator experiments and outcomes indicated that the length of experience in ship handling and prior training influenced DPOs performance. The study concluded that DPOs should take more effective training to maintain proper positioning for the safe operation of DP vessels.

1 INTRODUCTION

1.1 *Characteristics of DPS and DPclass*

As an automatic position-keeping controller, i.e., the Dynamic Positioning System (hereafter DPS), maintains vessel's position by automatically controlling the power supply, thrusters and other propulsion equipment [1]. The International Maritime Organization (IMO) defines three classes of DPS based on their degree of redundancy: classes A, B and C. In Japan, the classification society, Nippon Kaiji Kyokai (Class NK), established three identical classification codes. DPclass A holds a significant share of the global DPS market, primarily due to its lower cost and the minimal design standards required for DP operation compared to DP classes B and C. In contrast, DP classes B and C are more expensive but offer greater redundancy, ensuring that a single system failure does not result in total system failure. Notably, DP class C can maintain the vessel's stability in a serious incident, such as installation compartment loss due to fire or flooding [1]. In contrast, DP Class Ahas no redundancy, meaning a single fault could lead to a loss of position. Consequently, the reliability of the three DP classes varies [2].

1.2 *DP Vessel Marine Incidents*

The percentage of maritime incidents due to inaccurate positioning of DP vessels has been increasing since 2019 and continues to rise (2015–2023; see Figure 1) [3, 4].

These incidents often entail DPS-equipped vessels being in incidents due to incorrect positioning information from the Global Navigation Satellite System (GNSS) and other sources. Inaccurate positioning can result in drift-off (vessel position deviation due to power failures, generator issues or

power supply failures), drive-off (deviation from the target position due to inaccurate GNSS data) and force-off (deviation caused by external forces), among others [5].

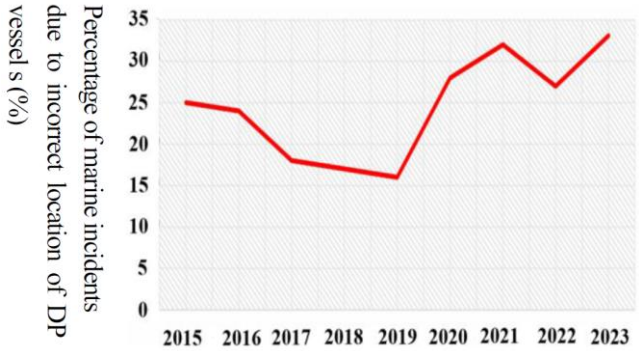

Figure 1. Percentage of marine incidents due to incorrect location of DP vessels (2015～2023)

Marine incidents on DP vessels are attributed to several factors, as illustrated in Figure 2 [6]. Thruster (propulsion system) and computer (information processing system) failures account for over half the marine incidents on DP vessels. Other contributing factors include power (output system), the position reference system, humans (human element) and the environment (environmental element).

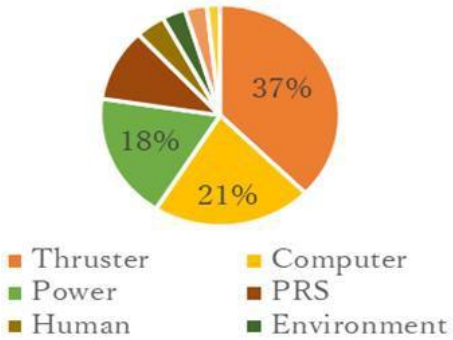

Figure 2. Causes of marine incidents on DP vessels (2023, n = 1230)

1.3 *Significance of Human Resource Development on DP Operations*

Previous research has shown that operators must possess appropriate seafarers skills to operate ships safely and handle all potential situations efficiently [5, 7].

Accumulating sufficient experience to develop a sense of ship handling through actual ship experience is a complex task for operators [8]. Hence, ship-handling simulators are an effective means of supplementing experiential learning for inexperienced operators [9].

Training to improve emergency ship handling skills is also considered necessary to hone skills [5], including responding to rare accidents on board, such as emergency responses following an accident [2, 5] or escaping from a crisis to avert a near accident [9].

The Certification and Accreditation Standards, Volume 1 - Training and Certification, published by the Nautical Institute (hereafter NI), an international professional body for maritime professionals, identifies Dynamic Positioning Operators (hereafter DPOs) as pivotal to meeting safety standards. These operators must possess the confidence, competence and experience to respond appropriately to major DPS failures. The DP Emergency Ship Handling Course is designed to equip malfunctions [10].

1.4 *Purpose of this Study*

A review of previous studies has highlighted the increase in maritime incidents attributed to the incorrect positioning of DP vessels [4,5,8]. Several factors have contributed to these accidents [5, 8]. Until May 2022, domestic DP simulator training was not conducted in Japan, leaving young DPOs without the necessary training in crisis prevention maneuvering techniques. The inability of inexperienced DPOs to develop these essential skills highlighted a significant training gap, particularly in Japan's maritime environment [11]. Given these realities, this study aims to identify how changes in position information affect emergency DP operations conducted by DPOs. The study explores which DP operation features help mitigate the risk of collisions and examines measures to enhance DPO skills in emergencies. A simulator experiment was conducted with DPOs to assess their ability to avoid collisions with offshore structures under diverse conditions to achieve this objective. A results analysis yielded fundamental insights for the development of training methods. Ultimately, the aim is to gather pivotal data as input for improving training and the current DPS training scenario needs to consider that the content of a given task is of cumulative importance to training and experience.

2 EXPERIMENTAL METHOD

2.1 *Devices used in the experiment*

2.1.1 *DPS Simulator*

The DPS used in the experiment was manufactured in Japan and the same system was installed on oceanographic research vessels and other types of ships. These DP vessels are equipped with bow thrusters and two stance thrusters (No. 1 and No. 2), a controllable pitch propeller (CPP), a rudder and two GNSSs: GNSS No. 1 (primary) and No. 2 (secondary). Additionally, the vessels have two main generators and one shaft generator. Three video cameras were positioned to capture the experimental footage: one behind the ship handling simulator, one in front of the participant's ship handling table and one behind each participant in the study. Participants were also equipped with an eye-tracking device to monitor their gaze.

2.1.2 *Monitoring function*

The DPS simulator is illustrated in Figure 3. It consists of an instructor's console on the left and a participant's console on the right. During the experiment, authors used a timer to record the measured time, distance from the offshore structure to the DP vessel, and speed and position while monitoring the display at the instructor's table. Meanwhile, the participant performed DP operations,

observing the four monitors (Figure.4-6) positioned in front of the console.

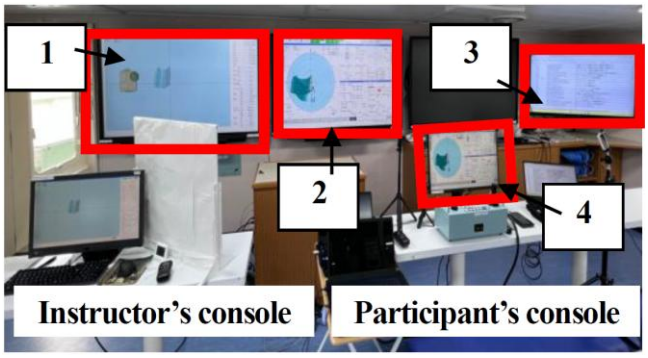

Figure 3. DPS Simulator

The details of forwards screen 1 and 2 are illustrated in Figure 4. Screen 1 illustrates the DP vessel's track chart, which can be viewed on the same view as the instructor's console. Screen 2 is displayed in Figure 4, comprising a main screen on the left and a sub screen on the right. The main screen allows selection from one of the eight items, while the sub screen offers four options from 19 items.

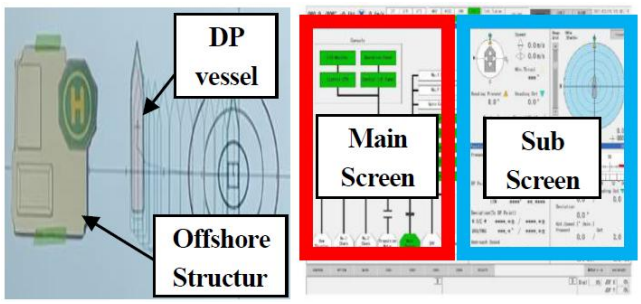

Figure 4. Screen 1(Left figure) & Screen 2 (Right figure)

2.1.3 *Alarm Device & Remote Control Box*

The DPS simulator's forwards screen 3, illustrated in Figure 3, alerts the user to the alarms, of which there are two types: system and operational. System alarms indicate equipment malfunctions and other issues related to the DPS. In contrast, operational alarms provide information pertinent to DP operations, such as deviations between the actual heading and set heading.

Figure 5 illustrates forwards screen 4, which can be correlated with forwards screen 1, as it displays the DP vessel's track chart. Additionally, forwards screens 4 and 2 are identical.

Figure 5 illustrates the remote control box used in the experiment, featuring a turn dial, a joystick and a button for switching between the DP operation modes, as illustrated in Figure 5.

Figure 5. Forwards screen 4 (participant's console screen) & Remote Control Box

2.2 *Participants*

The participants' profiles are indicated in Table 1. Nine DPOs participate in the experiment: four from a marine survey company and five from a marine engineering company. Their ages ranged from 27 to 45 years, with a mean age of 32 ± 5.8 years. The years of experience operating a DPS at sea ranged from 0.7 to 9.0 years, with a mean experience of 3.0 ± 2.4 years. In Japan, seafarers must meet specific experience requirements to operate a DPS [1]. Table 1 illustrates that all participants met the DP class A operating experience.

Table 2 presents the participants' training and ship handling history. Five participants completed the DPS training provided by the manufacturer, while another five had experience in emergency response. Additionally, eight participants had experience DP operation by a single.

Table 1. Participant profiles

DPOs	Age	Years of experience (Boarding)	Years of experience (DP operation)	DPS class	Rank
A	28	2 years 5 months	1 year 11 months	A	3/O
B	27	1 year 4 months	1 year 1 month	A	3/O
C	27	–	2 years	A, B	2/O
D	35	–	9 years	A, B	1/O
E	35	–	1 year 6 months	B	2/O
F	45	–	3 years	A, B	Capt
G	28	–	3 years	B	2/O
H	28	10 months	8 months	A	3/O
I	36	1 year 5 months	1 year 2 months	A	2/O

Table 2. Participant's training & ship handling history

Participants	NI Training (end of the day)	Experience in emergency response	Single DP operation
A	×	×	○
B	×	Control screen freeze, GPS signal disruption, etc.	○
C	Basic (2020.2.21)	×	○
D	Advance (2014.1.10)	Thruster & generator stop, etc.	○
E	Basic (2021.2.17)	×	○
F	Basic (2019.3.15)	Uncontrollable main azimuth thruster etc.	×
G	Advance (2022.9.2)	Out of position, suspend the use of stern thrusters, etc.	○
H	×	×	○
I	×	GPS anomalies	○

2.3 *Criteria and Setup contents of the experimental task*

2.3.1 *Setting criteria and items*

The criteria for establishing the experimental tasks were based on the emergency response plans and procedures outlined in the class NK guidelines [12]. The number of domestic offshore structure construction is less common than its European counterpart. Factors such as domestic weather conditions, work stoppage criteria and unique regulations (e.g. the Ship Safety law) complicate directly applying European standards. Therefore, by setting the experimental task criteria to align with the characteristics of domestic marine structure, the authors believe that they can contribute to preventing incidents in advance. The emergency response plan should include the following, as necessary: (a) emergency arrangements (communication network), (b) adverse weather conditions (including strong winds, lightning, etc.), (c) earthquake or tsunami, (d)pre- determined limits of structural parameters, (e)predetermined limits of resilience (or stability) parameters, (f)DPS-related matters, (g) structural or equipment damage, (h)mechanical, electrical or control system failure, (i) fire, (j)collision, grounding, (k) leakage, flooding and (l) personal injury [12]. The experimental setup was designed to prepare for these scenarios, assuming the operational tasks of a DP vessel necessary for emergency response. All participants consecutively performed Tasks 1–4 to assess their emergency response and operational skills in handling a near-accident crisis. Domestic marine structure has anti-collision measures in sea area and Marine Warranty Survey agree- d [12]. The four tasks are illustrated in Figures 6–9.

2.3.2 *Task 1*

Task 1 is illustrated in Figure 6. The DP vessel begins 150 (m) from the offshore structure, indicated by the red circle at the top of the diagram. As the DP vessel departs, it approaches the offshore structure without equipment failure. However, one stern thruster fails after the vessel has travelled 50 (m) (noted by the orange circle). Consequently, the vessel has only the bow thrusters and one functioning stern thruster. DP vessels must avoid collisions with the offshore structure, maintain a minimum distance of 100 (m) from the departure point and stop at least 50 (m) away laterally from the offshore structure. The end point is marked by the red circle in the diagram in Figure 6.

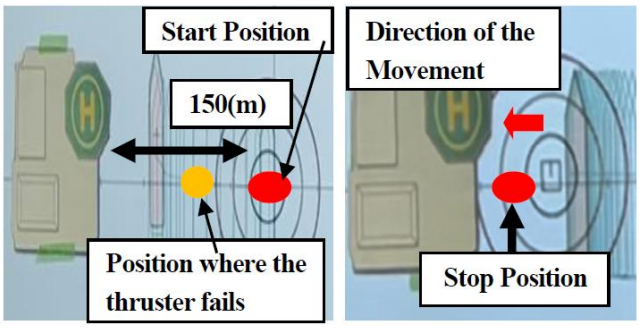

Figure 6. Task 1 (Left figure: Start position of the DP vessel; Right figure: Stop position)

2.3.3 *Task 2*

Task 2 is illustrated in Figure 7. Once the DP vessel reached a position 50 (m) lateral from the offshore structure, the stern thruster was activated, allowing the vessel to commence Task 2 while positioned east of the structure. During the experiment, DP vessels maintaining a fixed point were exposed to steady (northeast direction, less than 10 (m/s)) and gusty wind (northeast direction, 10 (m/s)). Each measurement period lasted 5 (min). The DP vessels must move away if they are close to prevent collisions with offshore structures. They are also expected to maintain a fixed position for approximately 10 (min). The DPO must also contact the individual in charge of the offshore structure if the vessel departs from its vicinity.

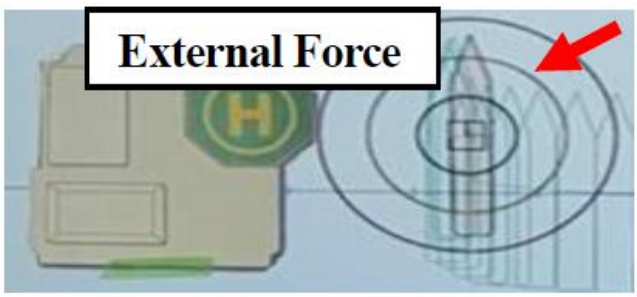

Figure 7. Task 2 (DP vessel with gusty wind)

2.3.4 *Task 3*

Task 3 is illustrated in Figure 8. After the DP vessel maintained a fixed position, a failure occurred in its GNSS (No. 1/No. 2) when it was 100 (m) away from the offshore structure. This failure led to inaccurate positioning information for the DP vessel. The DPO attempts to hold a fixed position but must also execute an emergency breakaway to prevent colliding with the offshore structure; thus, the DPO directs the vessel to move to a position 100 (m) away. Following the DPO's emergency departure, the DP vessel was moved to the designated distance, but the GNSS (No.1/No. 2) subsequently malfunctioned.

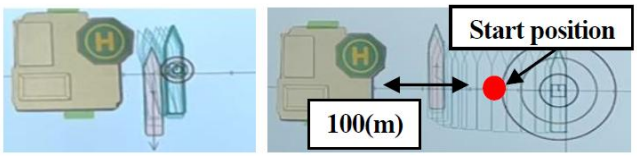

Figure 8. Task 3 (Left figure: emergency leave; Right figure: start position)

2.3.5 *Task 4*

Task 4 is illustrated in Figure 9. Once the GNSS position information was confirmed as accurate, the experiment began in an environment free of equipment malfunctions involving the DP vessel and external forces. On short notice, the individual in charge of the offshore structure contacted the DPO regarding transferring an injured person and instructed him to approach the offshore structure. Measurements were collected from the point where the DP vessel received these instructions. The DPO manoeuvred the DP vessel to turn around and approach the offshore structure. The DP vessel had to stop, rotate its bow heading to the south and maintain a lateral distance of 50 (m) from the offshore structure to avoid a collision.

Figure 9. Task 4 (Left figure: pivot-turn manoeuvring; Right figure: final position of the DP vessel)

2.4 *Experimental procedure*

After explaining the experiment, the participants engaged in the DP operation for approximately one hour to familiarize the system. The experiment was conducted between 13:00 and 17:00 to account for the influence of circadian rhythms on the data. The participants performed DP operations while seated at their consoles, viewing the four monitor screens in front of them. While the participants operated the DP system at their consoles, the authors assumed the roles of captain, chief engineer and person in charge of the offshore structure at the instructor's console. When necessary, the participants communicated via a transceiver with the captain, chief engineer or person in charge of the offshore structure.

The participants manoeuvred the vessels using four DP operation modes: STANDBY (standby), JOYSTICK (manual), AUTO HEAD (semiautomatic operation, where only the bow is automated and the DP operation is conducted via JOYSTICK) and AUTO DP (fully automatic operation).

2.5 *Preliminary Experiment*

A preliminary experiment was conducted with students from a seafarers' training institute to develop research items focused on collision avoidance decision-making for DP vessels [13]. The DPS simulator was verified to be functional before the experiment. Figure 10 illustrates the preliminary experiment.

Figure 10. Preliminary experiment

The collision avoidance decision-making research items listed in Table 3 were established using the results of the preliminary experiments. Ten items were examined for collision avoidance decision-making for each task. During the preliminary experiments, the order of the research items for collision avoidance decision-making varied across tasks. The following section details the items investigated for collision avoidance decision-making.

Table 3. Collision avoidance decision-making research items

Task 1	Setting the DP point Alarm confirmation Range adjustment Switching the sub screen Generator check Radio communication Switching the operation mode Speed Switching the main screen Sensor check	Task 2	Switching the operation mode Heading Setting the DP point Use of capability plot Switching the sub screen Radio communication Range adjustment Emergency avoidance Speed Switching the main screen
Task 3	Alarm monitoring Switching the operation mode Switching the main screen Setting the DP point Radio communication Sea transfer Switching the sub screen Sensor check Speed Range adjustment	Task 4	Setting the DP point Speed Heading Setting of the DP Circle Radio communication Alarm monitoring Switching the operation mode Switching the sub screen Gain adjustment Range adjustment

The DP point and DP reference point are illustrated in Figure 11. The DP point, represented by a square mark, is designated by the DPO to maintain the DP vessel at a fixed location and is identified as the DP reference point (illustrated as a blue circle). The DP reference point is where the DPO must ensure the DP vessel remains. The DPO can adjust the DP point and DP reference point settings. The DP point operation screen, highlighted in the red frame in Figure 11, is organized into categories: latitude and longitude, bearing and distance, north, south, east and west and UTM coordinates (Universal Transverse Mercator, projecting the Earth's coordinates onto a planar view). The DP point can be modified by entering the desired coordinates on the screen on the red frame.

Changes to the DP reference points are illustrated in Figure 12, with the operation screen on the left and the coordinate system on the right. The operation screen is organized into five categories from top to bottom: Reference Point (hull reference point), BT Winch (winch), CTD (Conductivity Temperature Depth: oceanographic instrument), A-frame and Key-in (numerical input). The coordinate system is presented on the right side of Figure 12, specifying the x- (m) and y-coordinates (m) for each item on the operation screen. Consequently, the DPO can select from these five items. Once the DPO has input the changes for the DP point, the adjustments on the confirmation screen (latitude and longitude) for the DP point operation can be reviewed, as illustrated in Figure 13 (Left figure). After entering the DP reference point change, the DPO updates the DP reference point on the operation check screen, as illustrated in Figure 13 (Right figure).

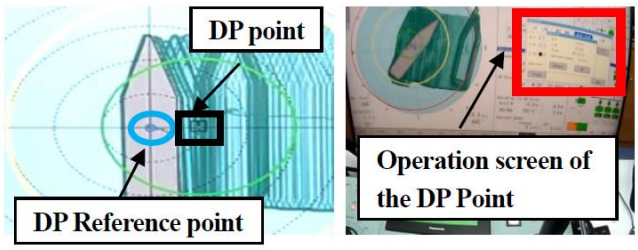

Figure 11. DP point & DP reference point (Left figure) & Operation screen of the DP point (Right figure)

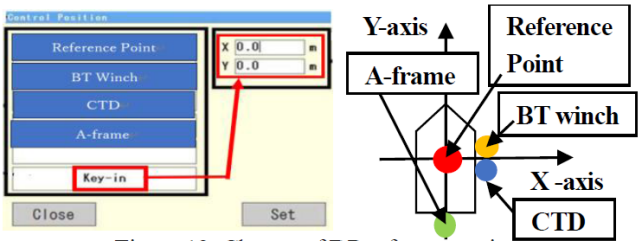

Figure 12. Change of DP reference point

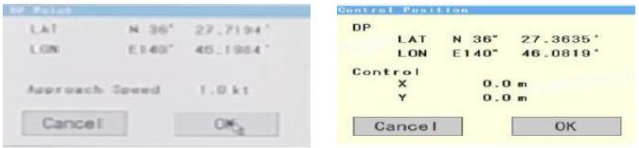

Figure 13. Operation check screen (Left figure: DP point; Right figure: DP reference point)

'Radio communication' refers to the DPO's use of a transceiver to contact the captain, chief engineer or person in charge of the offshore structure. 'Alarm confirmation' denotes the DPO's verification of the system and operational alarms within the DPS. 'Range adjustment' involves the DPO altering the scale of the DPS screen by using the top left slide bar, as illustrated in Figure 14. Speed refers to the DPO's adjustment of the DP vessel's movement in the vector direction. The setting of the speed is illustrated in Figure 14. When the vessel operates in the AUTO DP mode, the DPO can adjust the vessel's speed by inputting the desired speed into the screen highlighted in the red box in Figure 14.

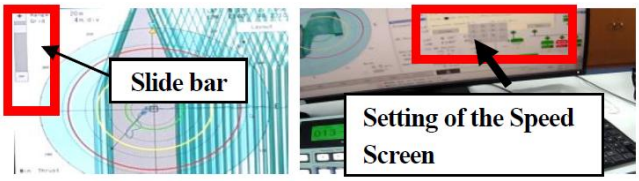

Figure 14. Range setting (Left figure) & Setting of the speed (Right figure)

The main screen and the sub screens are displayed in Figure 15. 'Switching the main screen' refers to the DPO's implementing a single main screen change. The DPO switches sub screens by selecting four out of the available 19 sub screens and implementing the necessary changes to these four.

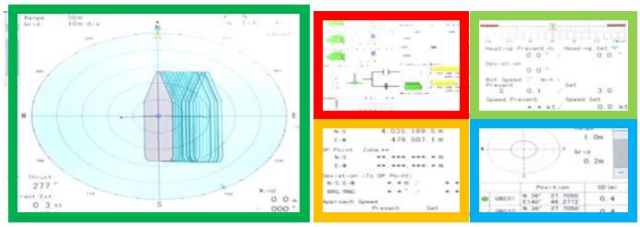

Figure 15. Main screen (Green frame) & Sub screens

The 'generator check' requires the DPO to verify the output values of the two main generators and one shaft generator.

The 'sensor check' requires that the DPO ensures the position sensor and GNSS (No.1/No.2) are functioning correctly.

The 'heading' indicates the change in the bow heading of the DP vessel as managed by the DPO.

'Emergency avoidance' refers to DPO utilizing the operational mode for an emergency evacuation.

Figure 16 illustrates the capability plot. This theoretical simulation graph corrects for noise in the observed values. It provides an estimate based on weather, sea conditions and the DP vessel's capabilities (e.g. number of thrusters) [14, 15].

Theoretical simulation graphs identify new propulsion systems and sudden disturbances, estimate bow heading and determine position deviations. DPOs use capability plots to understand the limitations of these indications DPOs should not place excessive trust in the estimates provided by capability plots, however, as they do not accurately reflect the actual field environment.

Figure 16. Capability plot

'Alarm monitoring' is the DPO's response to the DPS information regarding the system and operational alarms. For instance, if an 'Out of Red Circle' alarm occurs (indicating that the position is outside the red circle), the DPO corrects the issue by repositioning the vessel within the red circle.

A 'sea transfer' occurs when a DPO moves a DP vessel from one position to another.

The DP circle is illustrated in Figure 17. The centre of the DP circle represents the DP point, while the 'Setting of the DP circle' involves the DPO establishing three concentric circles. These circles are defined by the allowable radii of the red, yellow and green circles. The green circle is the closest to the DP vessel, the yellow circle is the second closest, whereas the red circle is the furthest away. The DPO manoeuvres the DP vessel to ensure it remains within these designated circles.

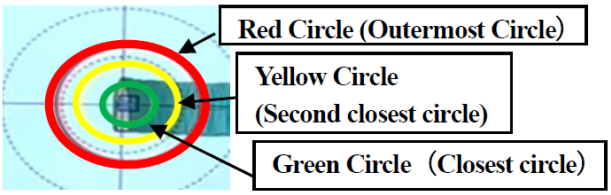

Figure 17. DP circle (alarm circle)

Figure 18 illustrates the gain setting screen. The gain adjustment process requires the DPO to modify the dimensional and PD gains. Dimensional gains control the movement of the DP vessel in the forwards/backwards, left/right and turning directions. In contrast, the PD gains refer to the proportional (P) and derivative (D) gains for these same directions. These two gains apply only to semiautomatic and fully automatic operation modes. 'Switching the operation modes' entails the DPO changing among the four operational modes of the DPS. Figure 18 illustrates the screen displaying the GNSS (No.1/No.2) malfunction in the STANDBY mode. This screen is characterized by the position information (e.g. latitude, longitude) changing to red and accompanied by activating an alarm.

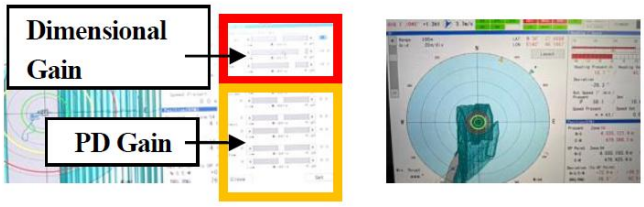

Figure 18. Gain setting screen (Left figure) & The screen of GNSS (No.1/No.2) malfunction (Right figure)

3 RESULTS

3.1 *Experiment (Task 1)*

Table 4 indicates the experimental results categorized by research items and participants. Results in Table 4 are marked with a ○ if all participants completed 10 of the research items based on the information obtained from the four forwards monitor screens; conversely, they are marked with a ● if they were unable to do so. All participants performed the research items without issues, except for the 'speed' item. The speed varied from 0.1 (kt) to 0.7 (kt) for all participants who had attended the training and maintained a low 'speed'.

Table 4. Experimental results by Research items (Task 1)

	Research items	A	B	C	D	E	F	G	H	I
Task 1	Setting the DP point	○	○	○	○	○	○	○	○	○
	Alarm confirmation	○	○	○	○	○	○	○	○	○
	Range adjustment	○	○	○	○	○	○	○	○	○
	Switching the sub screen	○	○	○	○	○	○	○	○	○
	Generator check	○	○	○	○	○	○	○	○	○
	Radio communication	○	○	○	○	○	○	○	○	○
	Switching the operation mode	○	○	○	○	○	○	○	○	○
	Speed	0.7	0.4	0.1	0.2	0.2	0.5	0.2	0.5	0.5
	Switching the main screen	○	○	○	○	○	○	○	○	○
	Sensor check	○	○	○	○	○	○	○	○	○

Under the 'speed' section, the set speed (kt) for those operating with the AUTO DP and set speed with the JOYSTICK is illustrated in Figure 19. The set speed of AUTO HEAD can be used in the JOYSTICK. The use of AUTO DP was five participants and the change in speed (kt) with the AUTO DP is illustrated in Figure 20. Participants C, E and G, each with three years or less of sea experience while operating with the AUTO DP, had set vessel speeds of less than 0.5 (kt). Participants C, E, G and H, each with three years or less of experience at sea, operated the DP vessel at a maximum speed of 1.6 (kt) or less, bringing it close to the offshore structure.

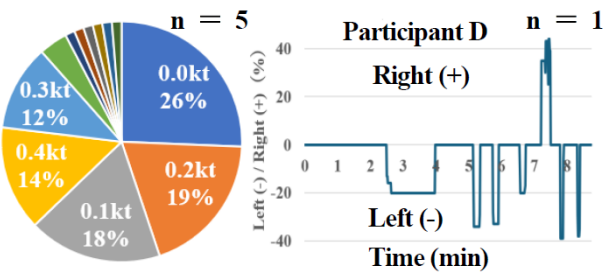

Figure 19. Set speed with the AUTO DP (Left figure) & Set speed with the JOYSTICK (Right figure)

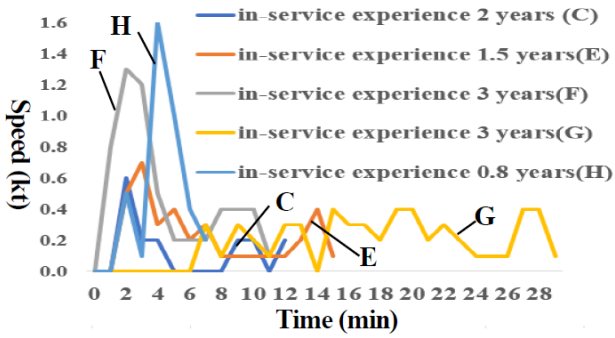

Figure 20. Change in speed operated with the AUTO DP

The change in speed (kt) with the AUTO HEAD is presented in Figure 21. Of the four participants while operating with the AUTO HEAD, Participant D, with nine years of experience at sea, operated the vessel at a maximum speed of less than 0.5 (kt). In contrast, Participants A, B and I, all with less than nine years of experience, exhibited a significant change in speed. With his nine years of experience and operating under the AUTO HEAD, Participant D showed a minimal speed change (kt). The results in Figure 19 (Right figure), 21 validate Participant D's AUTO HEAD (JOYSTICK) operation, who has extensive in-service experience. Participant D, while using the AUTO HEAD, successfully approached the DP reference point and halted the vessel by gradually reducing speed, setting the JOYSTICK to neutral in small increments, within 40% or less of the JOYSTICK output value (left/right direction).

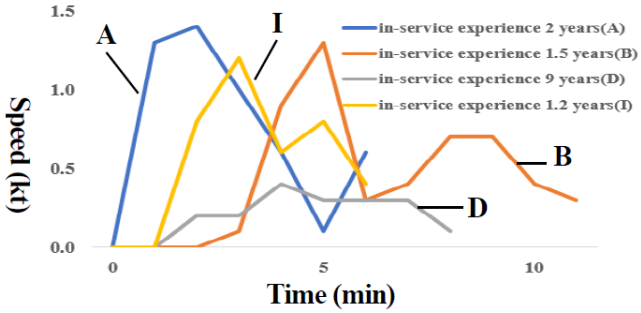

Figure 21. Change in speed operated with the AUTO HEAD

Figure 22 illustrates the deviation between the DP point and DP reference point for Participants C, E, F, G and H, all of whom had three years or less of in-service experience and operated in the AUTO DP mode. In these cases, the DP reference point position served as the hull reference point, meaning that the distance represented in Figure 22 corresponds to the distance travelled by the hull reference point. As these Participants adjusted the DP point's position, the DP point's distance reflected the distance travelled by that point.

Participants F and H, both with three years or less of sea experience and operating in the AUTO DP, set their DP points further from the DP reference point. This led to significant speeds towards the DP reference point due to the large deviation between the two. Furthermore, Participants C and F incorrectly entered the DP point settings within the first five minutes of the experiment. It was also noted that Participant G adjusted the DP point setting more than ten times, resulting in an extended DP operation time.

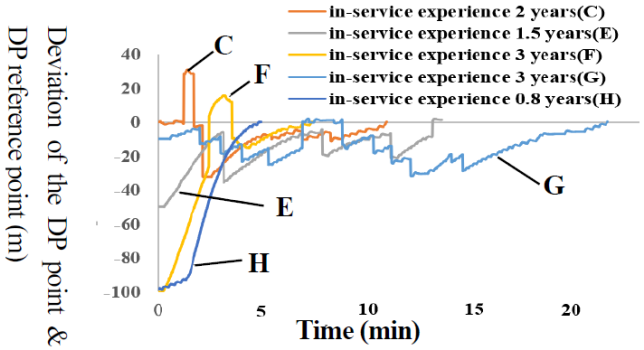

Figure 22. Deviation of the DP point & DP reference point maneuvered with the AUTO DP

Figure 23 illustrates the DP reference point for vessels operating in the AUTO HEAD mode is illustrated. For Participants A, B, D and I, who also operated in the AUTO HEAD, the distance to the DP reference point corresponds to the distance travelled by the hull reference point, as the DP and hull reference points are aligned. While Participants A, B, D and I stopped their DP vessels approximately 100 (m) from their intended stopping point, there was some variation in this distance.

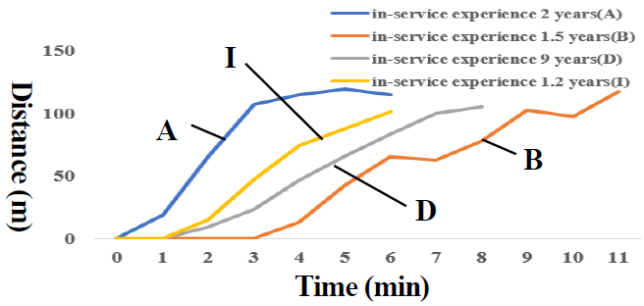

Figure 23. DP reference point manoeuvered with AUTO HEAD

3.2 *Experiment (Task 2)*

Table 5 presents the experimental results for Task 2, organized by research item and participant. In this table, the results are marked with a ○ if all participants successfully performed 10 research items based on the information obtained from the four forwards monitor screens; conversely, the results were marked with a ● if they were unable to do so. Eight participants, excluding Participant G, did not utilize the 'use of capability plot'. Additionally, Participants F and H could not complete four and six items, respectively, aside from the 'use of capability plot', while both failed to avoid the emergency. The time to switch modes illustrated in Figure 24. It was found that the time taken to switch the modes was less than 4 minutes from the occurrence of the external force until the collision with the marine structure. The research item in Task 2, 'Setting the DP points', was examined. Figure 24 illustrates the distance (in metres) from the DP vessels to the offshore structures. As illustrated in Figure 24, Participants A–I represent the nine DPOs operating the vessel in the AUTO DP.

Table 5. Experimental results by Research items (Task 2)

	Research items	A	B	C	D	E	F	G	H	I
Task 2	Switching the operation mode	○	○	○	○	○	●	○	●	○
	Heading	○	○	○	○	○	○	○	○	○
	Setting the DP point	○	○	○	○	○	●	○	●	○
	Use of capability plot	●	●	●	●	●	●	○	●	●
	Switching the sub screen	○	○	○	○	○	○	○	○	○
	Radio communication	○	○	○	○	○	○	○	○	○
	Range adjustment	○	○	○	○	○	○	○	●	○
	Emergency avoidance	○	○	○	○	○	●	○	●	○
	Speed	0.3	0.2	0.2	0.7	0.5	0.2	0.2	0.4	0.4
	Switching the main screen	○	○	○	○	○	○	○	●	○

They maintained a fixed position from the DP vessel to the offshore structure, typically at a distance of approximately 50 (m), although individual differences were noted. The DP vessel maintained a clearance of approximately 30 (m) or more.

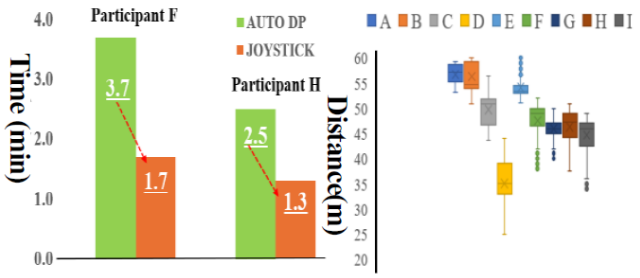

Figure 24. Time to switch modes (Left figure) & Distance from the DP vessel to the offshore structure (Right figure)

Figure 25 illustrates the deviation (m) between the DP point and DP reference point (defined as wind speed less than 10 (m/s)) as set by all participants. Each participant adjusted the DP reference point positions to align with the hull reference and DP points. The centre point (x: 0 (m), y: 0 (m)) in Figure 25 represents where the DP point and DP reference points overlap. The coordinate values (x (m), y (m)) indicate a smaller deviation (m) between the DP point and DP reference point, due to the steady wind conditions affecting the DP vessel. The results in Figure 25 suggest that all participants operated the vessel while actively changing the DP point and DP reference points, as evidenced by their lack of overlap. The deviation between the DP point and DP reference point was smaller for Participants F and G, who each had three years of experience at sea, compared to Participants A, B, C, E, H and I, all with less than three years of experience.

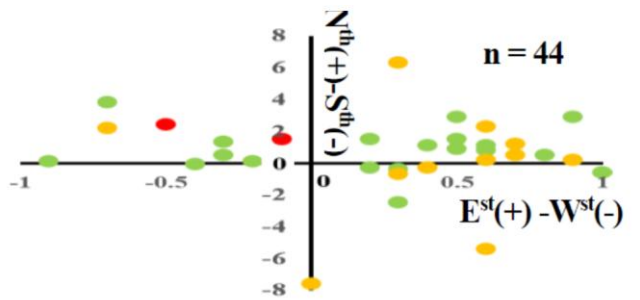

Figure 25. Deviation between the DP point and DP reference point (Experience at sea: red 9 years; green 3years; orange less than 3years)

The deviation between the DP point and the DP reference point (wind speed: 10 (m/s)) established by all participants is illustrated in Figure 26. The centre (x: 0 (m), y: 0 (m)) indicates where the DP point and DP reference point overlap. The coordinate values (x (m), y (m)) displayed a greater deviation between the DP point and DP reference point compared to those in Figure 25, because the DP vessel was affected by wind gusts. Participant D, who has 9 years of experience at sea, had a smaller deviation between the DP point and DP reference point. In contrast, Participants F and G, each with 3 years of experience at sea, demonstrated significant deviations, as did Participants A, B, C, E, H and I, with less than 3 years of experience at sea. Figure 27 illustrates the heading of the DP vessel at wind speeds of 10 (m/s). Participants D, E, F, H and I, who had less experience at sea, did not orient the bow of the DP vessel towards the windward side (northeast). This oversight resulted in a greater deviation (in metres) between the DP point and DP reference point.

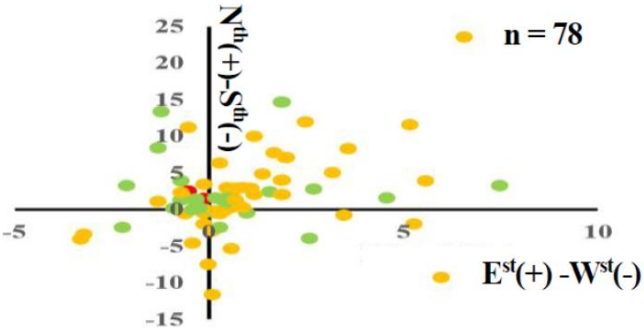

Figure 26. Deviation between DP point and DP reference(m) point (Experience at sea: red 9 years; green 3years; orange less than 3years)

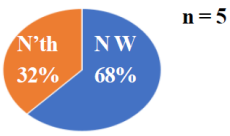

Figure 27.Heading of the DP vessel (wind speed: 10(m/s))

3.3 *Experiment (Task 3)*

Table 6 displays the experimental results for Task 3, organized by research items and participants. A ○ mark indicates that all participants successfully completed 10 of the research items using the information from the four forwards monitor screens; in contrast, a ● denotes they were unable to do so. Although all participants met the target for each item, there was variation in 'speed', ranging from 0.9 (kt) to 1.7 (kt).

Table 6. Experimental results by Research items (Task 3)

	Research items	A	B	C	D	E	F	G	H	I
Task 3	Alarm monitoring	○	○	○	○	○	○	○	○	○
	Switching the operation mode	○	○	○	○	○	○	○	○	○
	Switching the main screen	○	○	○	○	○	○	○	○	○
	Setting the DP point	○	○	○	○	○	○	○	○	○
	Radio communication	○	○	○	○	○	○	○	○	○
	Sea transfer	○	○	○	○	○	○	○	○	○
	Switching the sub screen	○	○	○	○	○	○	○	○	○
	Sensor check	○	○	○	○	○	○	○	○	○
	Speed	1.6	1.3	1.3	1.1	0.9	1.3	0.5	1.3	1.7
	Range adjustment	○	○	○	○	○	○	○	○	○

Figure 28 illustrates a scatterplot displaying the DP reference points for all participants during the 'sea transfer'. This scatter- plot also represents the hull reference point's position (coordinates (x(m), y(m))), as all participants used the DP reference point as their hull reference point. The centre of Figure 28, marked by the coordinates (x(m), y(m)), indicates where the GNSS (No.1/No.2) fault occurred. All participants were observed to have moved the DP vessel in various directions, switched to the STANDBY mode from the four operational modes and maintained their position near the DP vessel. Participants A, B, C, E, F, G, H and I, who each had three years or less of in-service experience, demonstrated a wider range of hull reference point positions, with the DP vessel remaining close to the centre of Figure 28. In contrast, Participant D, with nine years of in-service experience, had the hull reference point positioned approximately 20 (m) southeast of the centre of Figure 28, where the DP vessel was waiting in safe waters.

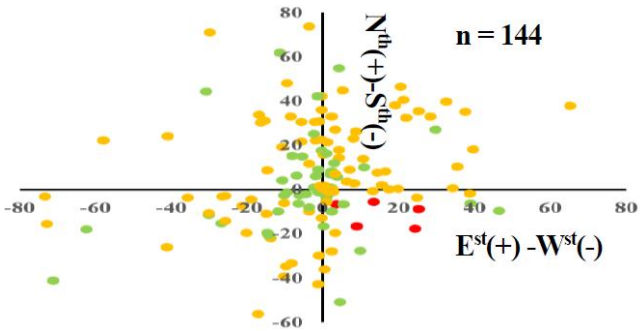

Figure 28. Scatter plot of the DP reference point (m) (Experience at sea: red 9 years; green 3years; orange less than 3years)

3.4 *Experiment (Task 4)*

Table 7 presents the experimental results for Task 4, organized by research items and participant. The results are marked as ○ if all participants could perform 10 of the research items based on information obtained from the four forwards monitor screens; conversely, ● indicated that they could not do so.

While all participants met the target for all items, there was variation in 'speed', ranging from 0.2 (kt) to 1.2 (kt). The research item 'speed' in Task 4 was examined, with the set speed (kt) while operating in the AUTO DP illustrated in Figure 29. It was observed that Participant D, with 9 years of experience at sea and Participants C, E and G, each with less than 9 years of experience, all set the speed to less than 0.5 (kt) as the four participants operating the vessel in the AUTO DP.

Table 7. Experimental results by Research items (Task 4)

	Research items	A	B	C	D	E	F	G	H	I
Task 4	Setting the DP point	O	O	O	O	O	O	O	O	O
	Speed	0.9	0.8	0.4	0.3	0.4	1.0	0.2	1.2	0.7
	Heading	O	O	O	O	O	O	O	O	O
	Setting of the DP Circle	O	O	O	O	O	O	O	O	O
	Radio communication	O	O	O	O	O	O	O	O	O
	Alarm monitoring	O	O	O	O	O	O	O	O	O
	Switching the operation mode	O	O	O	O	O	O	O	O	O
	Switching the sub screen	O	O	O	O	O	O	O	O	O
	Gain adjustment	O	O	O	O	O	O	O	O	O
	Range adjustment	O	O	O	O	O	O	O	O	O

The change in speed (kt) when using the AUTO DP is illustrated in Figure 29. The use of AUTO DP was four participants and Participants C, E and G, each with less than 9 years of in-service experience, adjusted their maximum speed to approximately 1 (kt), enabling them to bring the DP vessel close to the offshore structure. In contrast, Participant D, with 9 years of in-service experience, manoeuvred the DP vessel close to the offshore structure with speed below 1 (kt).

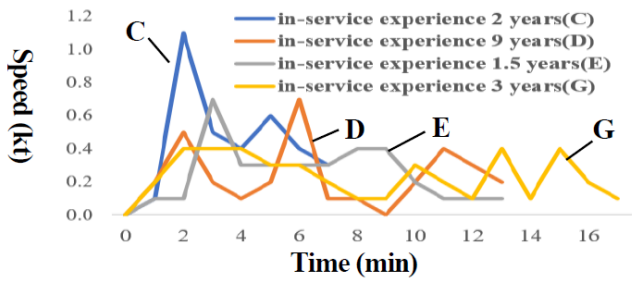

Figure 29. Change in speed operated with the AUTO DP

Figure 30 illustrates the change in speed (kt) while operating in the AUTO HEAD mode. Among the five participants who manoeuvred the vessel, Participant H, with less than one year of experience at sea, exhibited a greater change in speed.

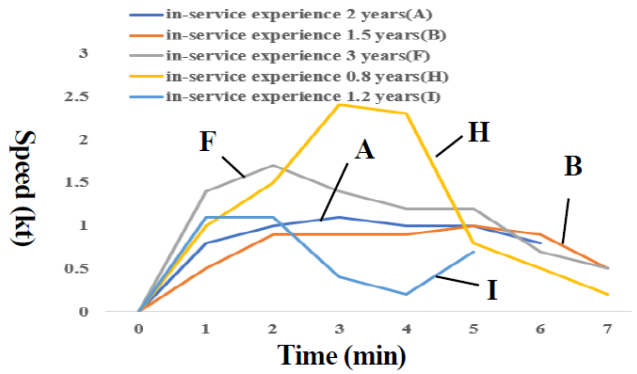

Figure 30. Change of speed manoeuvred with AUTO HEAD

The research item in Task 4, 'Setting the DP Point', was verified. The DP point and DP reference point, both operated with the AUTO DP, are illustrated in Figure 31. For Participants C, D, E and G, who operated the DP vessel, the distance of the DP reference point in Figure 31 is based on the hull reference point, which was used to set the DP reference point's position. Participants C, D, E and G adjusted the DP point's position; thus, the distance of the DP point in Figure 31 reflects the distance transferred by the DP point itself. Participant C, who has two years of experience operating a vessel with AUTO DP, observed that setting the DP point further from the DP reference point result- ed in a greater speed towards the DP reference point because of the increased deviation between the two points. Of all the participants (A, B, C, D, E, F, G, H and I), only those who reached the final point successfully completed the experiment.

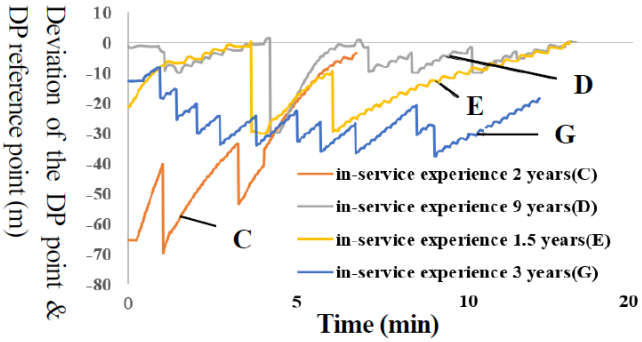

Figure 31. Deviation of the DP point & DP reference point manoeuvred with the AUTO DP

Figure 32 illustrates the DP reference point for the vessel operating in the AUTO HEAD mode. The distance indicated represents the distance travelled by the hull reference point. Participants A, B, F, H and I also operated with the AUTO HEAD and used the DP reference point's position as their hull reference point. Of these five participants, H, who had less than one year of experience at sea, moved the DP vessel a greater distance to reach the final location.

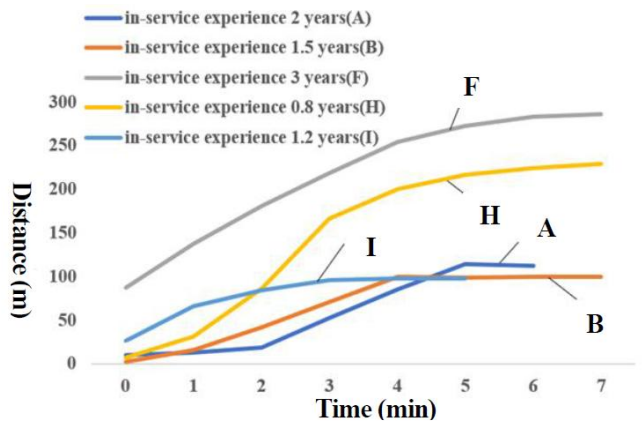

Figure 32. DP reference point manoeuvered with AUTO HEAD

3.5 *Status of achievement of task goals*

Table 8 presents the results of the task goal achievement by the participants. The results are marked as O if all participants successfully completed 11 of the research items based on the information obtained from the four forwards monitoring screens and as × if they did not. In Task 1, the items listed are 'Do not collide with offshore structure', 'Travel 100 (m) from the start point', and 'Stop at a position 50 (m) laterally away from the offshore structure'.

Task 2 includes the following items: 'Do not collide with offshore structures', 'If in proximity to an offshore structure, leave the offshore structure', 'The time for DP vessels to hold a fixed point is approximately 10 minutes', and 'If leaving an offshore structure, contact

the person responsible for the offshore structure'. Item of Task 3 is 'Move to a position 100 (m) away from the offshore structure'. The items for Task 4 are 'Stop to avoid collision with offshore structure', 'Heading is south', and 'Stop at a lateral distance of 50 (m) away from the offshore structure'. While all participants achieved the targets for all items in all tasks except Task 2, two participants failed to complete the item 'Do not collide with offshore structures', and five participants did not meet the requirement for 'Approximate time to hold the DP vessel at a fixed point for approximately 10 minutes' in Task 2. The failure in Task 2 for the item 'Do not collide with offshore structures' occurred because the joystick was not tilted forwards and right oblique (forwards and backwards: + (positive) %, left and right: + (positive) %) during the emergency avoidance operation, while Participant F tilted it backwards (forwards and backwards: - (negative) %, left and right: 0%) and backwards right oblique (forwards and backwards: - (negative) %, left/right: + (positive) %). Participant H tilted the joystick backwards and rightwards diagonally (forwards/backwards: - (negative) %, left/right: + (positive) %). It suggests that improper DP operation occurred due to the delayed switch modes and the shorter duration of JOYSTICK compared to AUTO DP. The five participants who failed to achieve the target of 'Approximate time to hold the DP vessel at a fixed point for approximately 10 minutes' did so because the bow of the DP vessel was directed northwest, causing a significant deviation between the DP point and DP reference point.

Table 8. Outcomes of task goal attainment by participants

	Task 1		
Participant	Do not collide with offshore structure	Travel 100 (m) from the start point	Stop at a position 50 (m) laterally away from the offshore structure
All	○	○	○

	Task 2			
Participant	Do not collide with offshore structure	If in proximity to the offshore structure, leave the offshore structure	The time for the DP vessel to hold a fixed point is approximately 10 minutes	If leaving the offshore structure, contact person responsible for the offshore structure
A	○	○	○	○
B	○	○	○	○
C	○	○	○	○
D	○	○	×	○
E	○	○	×	○
F	×	○	×	○
G	○	○	○	○
H	×	○	×	○
I	○	○	×	○

	Task 3
Participant	Move to a position 100 (m) away from the offshore structure
All	○

	Task 4		
Participant	Stop to avoid collision with offshore structure	Heading is south	Stop at a lateral distance of 50 (m) away from the offshore structure
All	○	○	○

4 DISCUSSION

4.1 *Discussion of the experimental results for Task 1*

For Participants F and H, a greater deviation occurred when the DP point was separated from the DP reference point, increasing the vessel speed. Therefore, it is crucial to be able to 'Setting the DP point' and DP operation training is essential in emergencies. In the event of a failure of one stern thruster on a DP vessel, the vessel must respond effectively to the command to 'Setting the DP point'. Regarding the ability to 'Setting the DP point', all participants met the target; however, Participant F had no prior experience with single DP operations, while Participant H had never received training and lacked experience in emergency response situations. In terms of 'speed', participants with prior training were able to maintain a low speed.

4.2 *Discussion of the experimental results for Task 2*

Participant G is the only individual who cleared the 'use of capability plot'. He had attended advanced training and had experience in emergency response. Conversely, among the two participants with multiple failures in areas other than the 'use of capability plot', Participant F had no history of operating a single DP operation. At the same time, Participant H had neither attended training nor had experience in emergency response. DPOs with less experience at sea displayed a significant deviation (m) between the DP point and DP reference point for external forces, particularly with wind speeds of 10 (m/s). When sudden external forces occur, it is crucial to manage the 'Setting the DP point effectively'. The timely implementation of 'Setting the DP point' by DPOs can help maintain clearance. Additionally, the DPO adjusts the 'Setting the DP point' to prevent collisions with offshore structures.

4.3 *Discussion of the experimental results for Task 3*

In the event of a GNSS (No.1/No.2) failure, the DP vessel must be manoeuvred in all directions from the point of failure. Therefore, 'Sea transfer' is crucial for DPOs with limited in-service experience. Participants A and I achieved speeds of 1.5 (kt) or more, despite not previously attending any training. Interconnections between two tasks is possible to highlight how the 'Setting the DP point' in task 1 related to performance in task 3. This demonstrates the cumulative importance of training and experience in emergency situations.

4.4 *Discussion of the experimental results for Task 4*

Participant C believed that 'Setting the DP point' was crucial because deviating more significantly from the DP reference point allowed for increasing the vessel speed. Additionally, if there is a change in instructions from the person responsible for the offshore structure, addressing the 'Setting the DP point' can ensure sufficient time to implement DP operations. Participants D and G, who had attended advanced training and possessed experience in emergency response, were able to meet the speed target.

4.5 *Discussion on the achievement status of the task goal*

Participant F, despite having experience in emergency response and holding the higher rank of captain, failed two items: 'Do not collide with offshore structure' and 'Approx. 10 minutes as a guide time for holding a fixed point on a DP vessel'. His performance may have been affected because less than four years had passed since he attended training, and he had no experience

operating a vessel alone—the only one to do so of the nine participants. Participant H, who also failed two items, had no previous training or emergency response experience and had only eight months of DP operation experience.

Participant D, a first officer, possessed nine years of experience in DP operations and emergency response experience, the longest in DP operations. Despite performing well in many of the research items, he failed to meet the requirement for the 'Approximate time to hold a DP vessel at a fixed point for approximately 10 minutes'. Additionally, it had been eight years and ten months since he completed the advanced training course. Of the other two participants who failed this item, Participant E had no experience in emergency response, while Participant I had never attended training.

4.6 *Limitations of the Study*

The study had some limitations, such as the simulator used in the experiment. Since this was manufactured in Japan, observing whether equipment manufactured in other territories produced similar results would be interesting.

5 CONCLUSION

The demand for maritime vessels with more flexibility and power requires that DP operations keep abreast of developments (16)and that the DPO's response to emergencies is aligned with these developments. The following conclusions can be drawn from the preceding discussion. First, factors such as attendance at training sessions, the time elapsed since completing training, years of DP operation experience and experience in emergency responses are perceived to influence participants' performance. For instance, Participant D's performance demonstrated that issues may occur in avoiding collision crises when experienced DPOs have not retrained for several years and lack adequate training in emergency response relevant to real marine scenarios. In response to this situation, the authors propose the following recommendations:

1. The training content established by the training center must be implemented for DP vessels to mitigate DPO human errors in conducting in adequate DP operations.
2. Retraining after a lapse of more than nine years should be mandatory for all DPOs.
3. (3) The simulator training content necessary for emergency response regarding 'setting the DP points' and 'sea transfer' must be revised. These contents were not included in the training content provided by the training center.
4. In simulator training for emergency response, the following objectives should be established:
   - In the event of a stern thruster failure on a DP vessel, the
   - 'Setting the DP point' must adjusted accordingly.
   - In the event of external forces (wind speed: 10 (m/s)), the
   - 'Setting the DP point' must be adjusted accordingly.
   - If a GNSS (No. 1/No. 2) fails, the DP vessel should be moved to safer waters.
   - If there is a change in the instructions from the person responsible for the offshore structure, the 'Setting the DP point' should be adjusted accordingly.

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