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CONFINED WATERS MANOEUVRING: CONFIDENCE MEASUREMENT OF TAIWANESE DECK OFFICERS

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CONFINED WATERS MANOEUVRING: CONFIDENCE MEASUREMENT OF TAIWANESE DECK OFFICERS

Hua-Zhi Hsu

Key words: ship handling, electronic chart, confidence measurement.

ABSTRACT

Navigational charts have been officially digitised for merchant shipping since 2010. Using an electronic chart is not as straightforward as using conventional paper charts. However, electronic charts provide a more efficient and sophisticated means of exchanging information for bridge system operators. Mariners should know how personnel aboard many vessels use navigational information. In this study, deck officers were invited to participate in a simulation experiment. A scenario of the entrance of a vessel into a busy fairway was simulated, and the participants were divided into two groups. The experimental group was allowed to use an electronic chart, and the control group had to use a conventional means of navigation. Significant differences were observed in the sweeping area and extent of the cross track error. The participants made fewer mistakes and had greater confidence in handling vessels when their precise position was electronically displayed. In addition, the participants were willing to receive information from an electronic chart system and, thus, felt comfortable when sailing in confined waterways.

I. INTRODUCTION

The Electronic Chart Display and Information System (ECDIS) assists officers of the watch (OOWs) in voyage planning, position plotting, and route monitoring (Conley, 2000; Norris, 2010). According to International Maritime Organization regulatory guidance, International Hydrographical Organization specifications, and International Electro-technical Commission test performance standards, the ECDIS eases the workload of the bridge lookout and provides accurate data for navigation (IMO, 1998; IHO, 2000; IEC, 2008).

The ECDIS is mandatory for several Standards of Life-saving at Sea (SOLAS) ships with a phased-in schedule according to the latest Standards of Training, Certification and Watchkeeping (STCW 78/95) (IMO, 1997). In short, deck officers are required to undergo approved training courses to obtain an endorsement that permits them to operate the system (IMO, 2010; UK P&I Club, 2012). This study examined the effects of the officers' performance, particularly in a confined navigational area. To determine the actual relationship of the interface between man and machine and an existing chart system, a simulation experiment was conducted. In this study, mariners demonstrated their capability in manoeuvring a ship according to the information that is displayed by the ECDIS.

II. SYSTEM OVERVIEW

A new aspect of the ECDIS was introduced for creating a safer, more efficient system by using an advanced design that integrates these characteristics into an electronic chart system (Norris, 2012). The layers of navigational information and the concept of e-navigation and its associated application to an electronic chart display will be discussed.

1. Information Layers

The predecessor of the ECDIS that is generally found on ship bridges today was introduced in the 1980s to more accurately plot a ship's position (Norris, 2010). Positioning data, supported by global navigation satellite systems (GNSSs), had only a horizontal accuracy of 100 m. The system was limited to the extent that it often displayed a ship's position on land when its position was actually at sea (offshore or in harbour areas). Therefore, a prudent mariner could not completely rely upon information from a chart display system when sailing close to a coastline.

The positional accuracy and reliability of navigational systems has improved markedly (Moore et al., 2003). Electronic navigational systems currently provide a horizontal accuracy of approximately 10 to 15 m. This acceptable level of accuracy can provide results superior to those of an ordinary chart.

For a watchman to fully understand nearby traffic, the in-

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formation should be relayed from the radar and visual lookout to the users (deck officers). An approved ECDIS can be divided into three parts: information layers, linked devices, and data input/output streams. An electronic navigational chart, radar scanned images, an automatic identification system, and other system components are required to assemble a fully recognisable real-time navigational image. However, choosing or adding an excessive number of information layers simultaneously might distract users. Excessive information could easily be provided to end users in this situation (Gale, 2009). To avoid information overload, system end users can choose a few layers of essential information. Furthermore, they can adjust and set these layers to a desired display when they are on watch.

The display system serves as a platform for information exchange, and the bridge system provides authentic information to the ECDIS (Bonnor, 2005). Bridge system components, namely a GNSS, a gyro compass, and a log, facilitate fixing a ship's position and observing various headings, vectors, and synchronised timing intervals.

2. Concept of E-navigation

Because layers of navigational data are available on the ECDIS, information from various navigational aids can be gathered and used easily by deck officers (Norris, 1998). The working principle behind the introduction of e-navigation to the ECDIS is that it can enhance the navigational capabilities of anyone who uses it (McCabe, 2010; Hagen, 2012; Sollosi, 2012).

ECDIS provides an operational platform that enables essential navigational data to be exchanged, processed, and produced in a synchronised manner (Norris, 2005). The flow of information is bilateral according to the principle of e-navigation. Information displayed on a vessel's screen could be as complete as the information provided by a traffic controller. In the near future, with technological advancements in radio communication and data processing, ships will be able to communicate and interact with other vessels and coastal stations more efficiently.

3. Applications in Confined Waters

One ECDIS application is to show the off track distance, that is, the cross track error (XTE), which indicates its degree of deviation during the execution of electronic route plans (Transas, 2006). The XTE contains two lines parallel to the planned route; a green line for the starboard side deviation and a red line for the port side deviation. Vessels are not warned until they cross either side of their XTE border lines.

Mariners determine the XTE setting values. For instance, the ECDIS in the experimental simulation had a default value of 0.1 nm on either side of the XTE limits (Fig. 1). A smaller scale of the XTE could result in frequent alarming of the manoeuvring deviation. By contrast, a larger scale of the XTE might not be able to pass the route verification by the system beforehand. In short, the XTE function supervises the travelling deviation and keeps all vessels out of danger zones along the planned route.

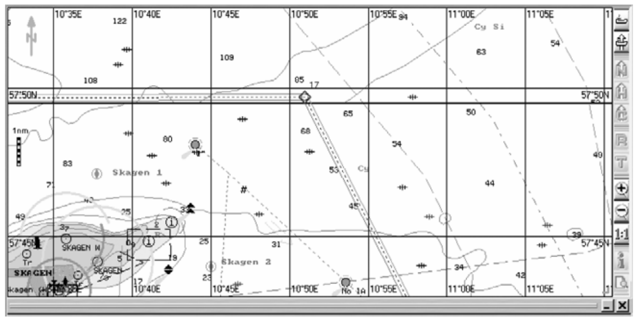

Fig. 1. Route with XTE (taken from the Transas User Manual).

III. SIMULATION PROCESS

Simulation experiments in which 25 participants completed exercises were conducted from the 9th of January to the 30th of May, 2011. However, only 20 of the participants, mainly Taiwanese deck officers, were considered to have valid results. The simulator was a TRANSAS NAVI-Trainer Professional 5000 ship handling simulator. Its suite contains two bridges and stations, which are monitored and controlled by the instructor. The following subsections describe six aspects of the simulation, namely the bridge control, the scenario, traffic design, simulation briefing and debriefing, grouping, and simulation limitations.

1. Bridge Control

The vessel used for the simulation was a 32,000-gross-ton container measuring 250 m overall with a 32-m beam (Transas, 2006). According to the backgrounds of the participants, the most frequent vessel type was the container ship. The scenario involved the ship entering inbound harbour traffic with the engine in standby mode throughout the exercise. In addition, the engine order telegraph was set to dead-slow ahead. This condition can enable the vessel to reach a maximum speed of 8 knots. Moreover, for such a slow speed, follow-up steering was active for rudder control.

2. Scenario

The participants sailed into the traffic lane near the pilot station of Keelung Harbour. A quartermaster was appointed to assist the OOW on the bridge. According to the Keelung Port Vessel Traffic Service Manual (Fig. 2) (Keelung Harbor Bureau, 2011), inbound vessels should proceed to the entrance of the traffic separation scheme (TSS) and continue sailing with a heading of 171° true to the TSS inbound traffic channel.

The own ship (Code: OS1) of the trial, shown in Fig. 3, had a heading of 270° true and began 1 nautical mile (nm) northeast of the entrance point. Once OS1 passed the Keelung Pilot Station (Waypoint 3), the exercise was discontinued.

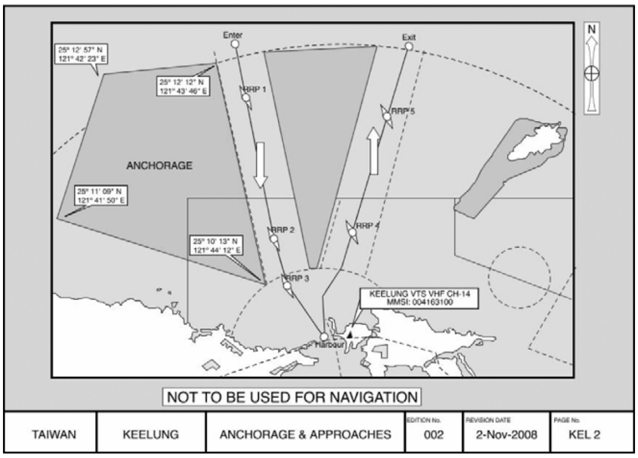

Fig. 2. The Keelung Port Waterways and Anchorage (Keelung Harbor Bureau, 2011)

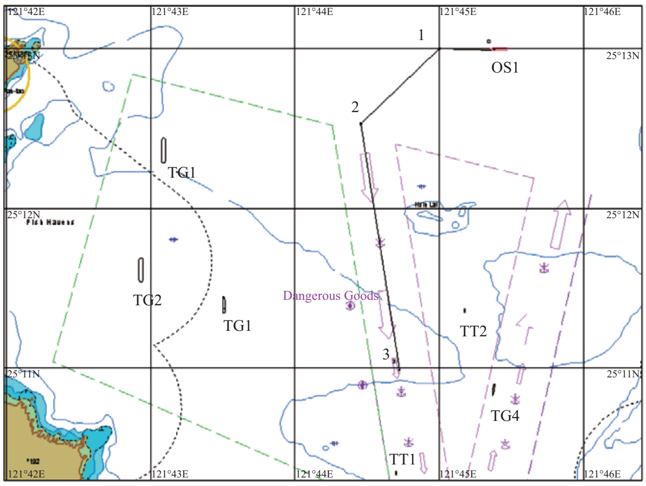

Fig. 3. The Scenario Design. (taken from the Instructor's station, Transas Simulator).

3. Traffic

To replicate an actual traffic scenario as closely as possible, a few target ships (Code: TG) were placed around OS1, as shown in Fig. 3. All TGs were not a cause for concern to OS1 as it made its approach. The traffic parameters for the simulation are listed in Table 1. The locations and conditions of all vessels are as follows: two bulk carriers (Code: TG1 and TG2) and a car carrier (Code: TG3) were anchored at the designated anchorage area; a destroyer (TG4) was present in the outbound channel; and a transit high speed craft (Code: TGN1) was heading westbound (315° true), northwest of OS1 with a 0.5-nm range. In addition, two tugs were present on location. The first tug, (Code: TT1) near the harbour entrance, assisted OS1 once the pilot was aboard. The second tug, (Code: TT2) in the TSS separation zone, was heading northeast. None of the TGs were programmed to distract the participants' ship handling.

Table 1. Nearby traffic.

Vessel code	Vessel type	Navigational Status	Cause Concern to OS1?
OS1	Container Ship	Underway using engine	-
TG1	Bulk Carrier	At anchor	No
TG2	Bulk Carrier	At anchor	No
TG3	Car Carrier	At anchor	No
TG4	Destroyer	Underway using engine	No
TT1	Tug	Underway using engine	No
TT2	Tug	Underway using engine	No
TGN1	High speed craft	Underway using engine	No

4. Briefing and Debriefing

Before the experiment began, the participants completed a questionnaire and were invited for a tour of the simulator suite. The designated quartermasters were then introduced to each participant.

The ARPA radar, conning panel, ECDIS, and paper chart thoroughly showed the movements of each ship and its operational procedures. Next, a warm-up session was held to ensure that all participants were familiar with the control of the simulator and the characteristics of OS1. Therefore, the participants could determine the length of the warm-up session. Because the vessel manoeuvred within a confined traffic lane in the scenario, quartermasters were present to man the bridge. However, the scenario was not designed to be a one-man-bridge situation.

When the simulation session ended, the participants shared their opinions on the simulation results. First, the onboard logbook was collected, and the history of OS1's track was then shown to the participants. Shortly afterwards, a brief discussion was held with the instructor regarding any opinion or any wrongdoing that occurred throughout the experiment.

5. Subgroups

The controlled variable was the use of the electronic chart display. The participants were evenly divided into two groups according to their current ranking. The groups were divided into an experimental group (EG) and a control group (CG). Only the EG could monitor an electronic chart display showing a planned route, which was identical to the passage plan for the paper chart. The CG had to fix the position on the ordinary chart regularly.

The only variable that was controlled in the experiment was the digital display of the planned route without the XTE function (Fig. 3). It was focused on the functionality of the

ECDIS and route monitoring system once OS1 passed the entry point.

6. Simulation Limitations

Unexpected bias was minimised in the simulation. Because the weather conditions were not considered controlled variables, the sea condition and visibility were fixed. The simulation began at noon. Weather conditions were considered reasonably fair with the wind blowing between 1 and 3 knots (force 1 on the Beaufort scale). In addition, the visibility was reasonable at 10 nm.

A full mission simulator (level one full-mission simulation suite) was established for creating the most realistic working environment possible (Carson-Jackson, 2010). However, a special purpose (level three) ship simulator was acceptable in certain simulation exercises, such as ECDIS operation. Because the simulation concerned only the examination of the bridge system, some limitations exist compared with a full mission simulation scenario. Furthermore, the view was limited to only 35°. A complete, unimpeded lookout would have to be developed to create a more realistic simulation of the conning tower.

A statistical test was conducted (Oppenheim, 1993; Flyvbjerg, 2001) to discover any significant differences in the controlled variable. Greene and D'Oliveira (1982) recommended employing the Mann–Whitney–Wilcoxon (MWW) test for two of the conditions and an unrelated design when different participants were used for each of them. In observations of few testing samples, Type I errors can be avoided by not using a *t* test (Siegel and Castellan Jr., 1988). The null hypothesis (Ho) proposed that the controlled variable does not differ between the two groups. Rejection of the null hypothesis indicates that the controlled variable affects the participants' behaviour while sailing in confined waters.

IV. RESULTS

The simulation results were based on data collected at the briefing session. Two data types, demographics and simulation records, were examined. Of the 20 participants, 16 succeeded in the trials of the Keelung Harbour approach and 14 samples were recognised as valid data at the end of the experiment.

1. Participants

Most of the participants (10 of 16) worked as deck officers for between 1 to 5 years (Table 2). The ratio of male to female officers was two to one, evidencing that a growing number of female Taiwanese deck officers serve onboard. Most participants had experience working aboard container ships, and 6 of 16 participants worked aboard liquefied cargo ships.

2. Ship Tracks

The OS1 tracks are shown separately in Fig. 4. Fig. 4(a) depicts the EG ship tracks acquired using the ECDIS, and Fig. 4(b) depicts the CG ship tracks acquired using only a conventional paper chart.

Table 2. Participants' background.

Ranking	Numbers	Sea time	Numbers
Master	1	11-15 years	1
Chief Officer	1	6-10 years	1
Second Mate	6	1-5 years	10
Third Mate	8	Less than one year	4
Total	N = 16	Total	N = 16

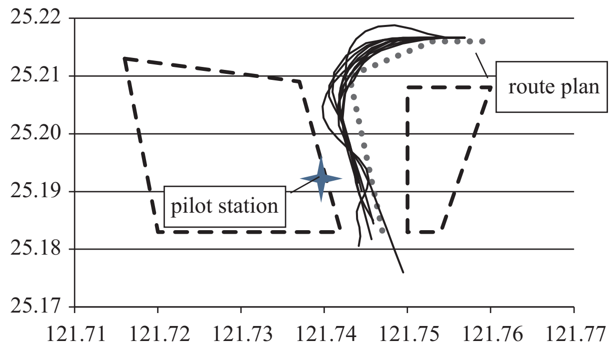

Fig. 4(a). The ships tracks (EG) result.

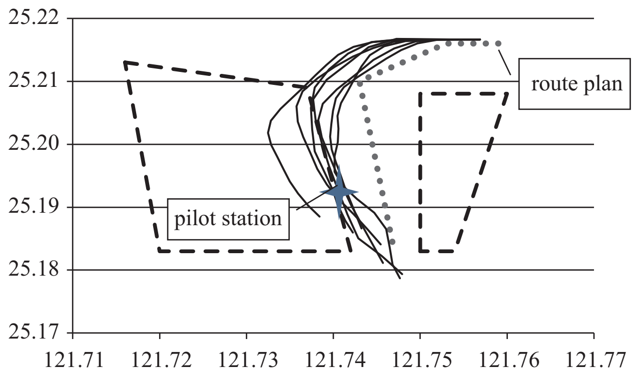

Fig. 4(b). The ships tracks (CG) result.

The EG managed to reach the entrance point of the inbound channel (Point 2 in Fig. 3) and maintained its track lines within the TSS traffic lane. By contrast, fewer CG participants managed to cross the boundary between the inbound traffic lane and the anchorage area. The EG (and with ECDIS on) more closely followed the passage plan than the CG did.

Because of the advantages afforded by a digital display of a planned route, a higher number of EG ships than that of CG ships approached a specific point, possibly a designated waypoint, rather than the point where they usually travelled. Freedom of sailing might not be possible in high-traffic waters.

In the future, such a scenario might pressure vessel traffic controllers by bringing vast numbers of merchant vessels into one area. The density of the traffic could increase markedly at certain periods of time after the ship route is published. In summary, the chart system might guide vessels towards certain waypoints in the future.

3. Debriefing Analysis

A few participants made apparent mistakes during the experiment. Two participants (EG) sailed towards a pilot station (dangerous goods pilot station) different from the station that was prescribed (Fig. 3). One participant (CG) decided to alter the course to give way to a tug that was ahead (TT1).

The orientation of ordinary charts is always north-up (Bowditch, 1995). Three participants (EG) mistakenly ordered the helm to port while transiting in the south-bound fairway. This was due to the disorientation of the ECDIS display, which was set as north-up, while OS1 was in fact heading south. This is similar to the scenario in which the radar is set to north-up when the ship's heading is in the opposite direction. These six results were considered void and not used.

V. ANALYSIS

Because few participants were analysed, the MWW test was adopted to determine whether any significant differences existed between the groups (Keller and Warrack, 1997; Dytham, 2003). To analyse the difference between the two groups, the maximum distance from the centre planned route (i.e., XTE) and the travelling area of OS1 were measured.

1. Nonparametric Statistical Techniques

Nonparametric techniques are adopted for comparing two populations of ranked data (Siegel and Castellan Jr., 1988). Because few samples were analysed (less than 10 participants from each group), the MWW test was conducted to determine any significance differences between the two groups (Anderson et al., 1999).

2. The Hypothesis

Regarding the ranking of the data, the hypothesis of the MWW test is as follows:

Ho: The two populations are identical with respect to the controlled variable.
Ha: The two populations are not identical with respect to the controlled variable.

A 5% confidence rate was required to reject the null hypothesis (H_o). Rejection of the null hypothesis denotes a significant difference in the controlled variable between groups.

3. Data

The XTEs (without XTE border line assistance) and sweeping areas (in yards squared) are listed in Table 3. The distances from the passage plan were measured once OS1 entered the inbound fairway. The EG achieved an average XTE of 0.94 nm. By comparison, the CG had an XTE of only 3.7 nm.

Table 3. The Off-centre distance and the sweeping area.

EG (ECDIS ON)			CG (CHART Only)		
Own Ship code	Off-centre distance	Sweeping area	Own Ship code	Off-centre distance	Sweeping area
1	0.9 nm	405 $yard^2$	8	3.1 nm	1395 $yard^2$
2	0.7 nm	315 $yard^2$	5	4.1 nm	1845 $yard^2$
26	1.2 nm	540 $yard^2$	11	2.8 nm	1260 $yard^2$
12	1 nm	450 $yard^2$	10	4.4 nm	1980 $yard^2$
17	1.1 nm	495 $yard^2$	14	2.5 nm	1125 $yard^2$
18	0.9 nm	405 $yard^2$	15	2.3 nm	1035 $yard^2$
22	0.8 nm	360 $yard^2$	16	6.7 nm	3015 $yard^2$
Key EG: Experimental Group; CG: Controlled Group; N = 14.					

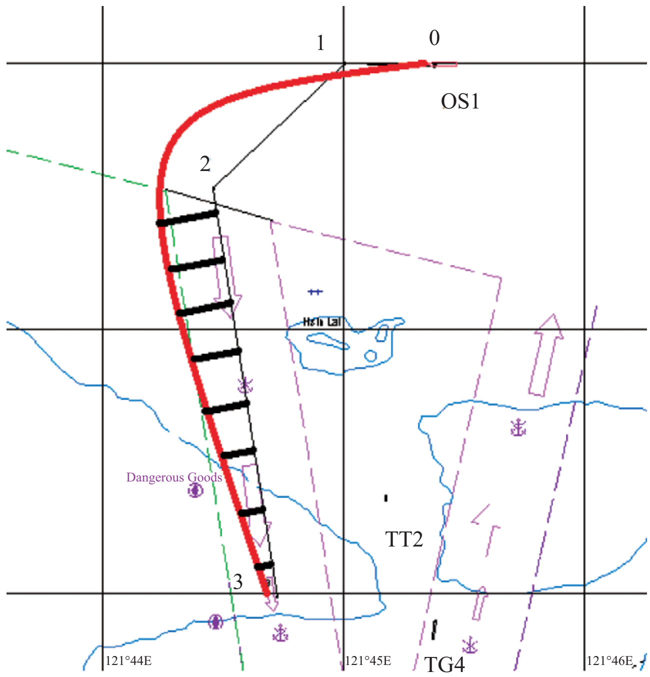

Fig. 5. The Measurement of the sweeping area.

Unnecessary travel should be avoided. Without a disturbance, vessels should follow their planned route. The concept of the sweeping area measure is shown in Fig. 5. A small sweeping area indicates that little time was spent on returning to the planned ship route. Thus, the adoption of a route or voyage plan apparently affects the handling of ships in congested waters.

4. Significance Test

As illustrated in Table 4, fourteen valid samples of the sweeping area were ranked and arranged in ascending order.

The most distinctive sweeping area results were then organised using a simplified ranked number system (Table 5). The data on the two groups were then summed and compared. The sampling distribution (T) for the EG (T_{EG}) was 28, and

Table 4. Sweeping area.

Ascending order	OS	Sweeping area
1st	2	315 $yard^2$
2nd	22	360 $yard^2$
3rd	18	405 $yard^2$
3rd	1	405 $yard^2$
5th	12	450 $yard^2$
6th	17	495 $yard^2$
7th	26	540 $yard^2$
8th	15	1035 $yard^2$
9th	14	1125 $yard^2$
10th	11	1260 $yard^2$
11th	8	1395 $yard^2$
12th	5	1845 $yard^2$
13th	10	1980 $yard^2$
14th	16	3015 $yard^2$
Key OS: Own Ship.		

Table 5. Sum of rank/sweeping area.

EG (ECDIS ON)				CG (CHART Only)			
OS	(nm)	($yard^2$)	Rank	OS	(nm)	($yard^2$)	Rank
1	0.9	405	3.5	8	3.1	1395	11
2	0.7	315	1	5	4.1	1845	12
26	1.2	540	7	11	2.8	1260	10
12	1	450	5	10	4.4	1980	13
17	1.1	495	6	14	2.5	1125	9
18	0.9	405	3.5	15	2.3	1035	8
22	0.8	360	2	16	6.7	3015	14
Sum of rank			$T_{EG} = 28$	Sum of rank			$T_{CG} = 77$

that for the CG (T_{CG}) was 77. For an overwhelming majority of rankings in the EG, T_L was equal to 28 (1 + 2 + 3 + 4 + 5 + 6 + 7). Hence, for the CG, T_U was 77 (8 + 9 + 10 + 11 + 12 + 13 + 14).

Critical values (Wilcoxon rank sum test for independent samples) were used, particularly because the sample size was smaller than 10 (Anderson et al., 1999). The values of T_L and T_U, which were 37 and 68, respectively, were obtained from a table of critical values. For event probability (P), the significance level is defined as follows:

$$\begin{cases} P(T \leqq T_L) = P(T \geqq T_U) = 0.05 \text{ or } 5\% \\ \therefore \text{ If } T < 37 \text{ or } T > 68; \text{ Reject } H_o \end{cases}$$

On comparing the sampling distribution (T_{EG} or T_{CG}) for both figures, we observed that the null hypothesis (H_o) was rejected. It was hypothesised that the controlled variable did not differ between groups at the beginning of this study. However, the hypothesis was rejected, indicating a significant difference in the controlled variable between the EG and the CG (Dytham, 2003). The controlled variable was the use of the ECDIS for route monitoring. The MWW test was conducted to determine the significance of the difference between the groups. The results indicate that mariners act differently depending on whether they accept the ECDIS.

VI. SUMMARY

As a mandatory operational system for most SOLAS vessels, the ECDIS is expected to ease the workload of officers and provide accurate data for navigation. In addition to facilitating chart navigation, the ECDIS has substantially more functions than conventional means of navigation do and serves as a sophisticated platform where information on bridge systems is exchanged.

This study evaluated the effects of the electronic chart display when the vessel was en route and monitored any occurrences by using a pilot station. Twenty participants were randomly selected and divided into two groups, and 14 samples were considered valid. The EG was allowed to operate the ECDIS, and the CG was allowed to use only a paper chart. The simulation modelled how the participants navigated in a traffic lane in confined waters with or without the ECDIS. Measurements of the tracks (Fig. 4) and sweeping area (Table 5) revealed differences between the groups. By using a statistical test, significant results were obtained and the null hypothesis was rejected. It is possible that the use of the ECDIS affected route monitoring performance in sailing according to the passage plan.

Deck officers using the ECDIS deviated from the route plan by less than 1 nm in confined waters. Conversely, deck officers with an ordinary chart deviated by almost 4 nm. It was concluded that the participants who used the ECDIS could follow the planned route more closely than other participants could. When using the ECDIS, Taiwanese mariners showed an increased degree of confidence in ship manoeuvring, particularly when sailing through confined waters.

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