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Fundamental Study of Evaluation at Berthing Training for Pilot Trainees Using a Ship Maneuvering Simulator

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ABSTRACT: Use of the ship maneuvering simulator (SMS) is at the core of pilot trainees education and training, so it is desirable to have an evaluation method that can be completed shortly after each berthing training session. There are basically two methods of docking maneuvering that pilot trainees learn: one in which the ship enters from outside the port and is berthed directly at the target quay, and a second method in which the vessel carries out a turn in front of the target quay before berthing. The authors suggested an evaluation index in a previous study concerning the first docking method. In the present study, the authors propose an evaluation method for the case of berthing the vessel using the turning maneuver. Since the index obtained by this method offers a single numerical benchmark, it is an easy–to-understand result of the training exercise. The authors carried out experiments using a SMS and confirmed that the proposed evaluation method is effective and helpful to improve the effectiveness of SMS training.

1 INTRODUCTION

Following the revision of the Pilotage Act in April 2007 in Japan, training of new pilots has started at the Tokyo University of Marine Science and Technology and other educational institutions. At the core of this training is the ship maneuvering simulator (SMS), a useful training tool capable of simulating basic ship maneuvers and special techniques for new trainees. There are basically two maneuvering methods used for ship docking. The first method is to enter the docking area from outside the port and berthing the vessel at the target quay directly. The second method involves carrying out a turn in front of the target quay, followed by berthing. In a previous study, the authors suggested an evaluation index that could be used to determine the efficacy of the training techniques for the first docking method (Inoue 2010, 2011). In this paper, the authors propose an evaluation method for the case of carrying out turn in front of the planning position and docking.

Turning the ship is typically done in front of the berth as a result of the planned maneuvering and can be done by the ship itself, in cooperation with tugboats or by use of anchors. For the present evaluation, the authors prepared a docking scenario involving a large pure car carrier (PCC). The difficulty in allowing for wind arises from the variable effect that wind can have on the high-side ships such as large PCC's, roll-on/roll-off ("Ro-Ro") cargo ships and container ships.

The experienced pilot recognizes the measurement information of many inputs, including ship speed, course deviation, and wind velocity, and steers the vessel while operating thrust controls such as the main engine and the rudder and monitoring the assistance of tugboats, all at the same time. This is possible because the skilled pilot has learned how to judge this large volume of information immediately, recognizing it from experience, and uses all information to properly control the ship maneuvers.

When examining the process of training pilots using SMS, the authors could not determine how trainees learn to sense overall patterns that were "normal" or "abnormal" as part of the standard SMS training. Therefore the authors examined the SMS training process using the concept of Mahalanobis-Taguchi System (MTS) method. (Tatebayashi K. 2004) (Elizabeth 2007). This approach utilized the data generated during the training to establish a quality index which may be used to determine training efficacy.

Since the index obtained by this method provides a simple numerical benchmark, it offers an easy-to-understand measure of training results. In this paper the authors carry out experiments using a SMS confirming that the proposed evaluation method is effective and helpful to improvement of SMS training.

2 TRAININIG SCENARIOS

2.1 *Port Information*

The port of Chiba is largest seaport in Japan, located in the interior of Tokyo bay. The port handles 166,964,000 tons of cargo annually from a total of 65,200 vessels. The training scenario involved the berthing a large PCC at this crowded port efficiently and safely. The berthing objective was Chiba F Quay; with a distance to the opposite quays of 720m.

Figure 1. Aerial-view of turning operation.

2.2 *Large PCC*

Maneuvering the large PCC was very difficult for the pilot trainees. The large PCC was a high-side ship with high freeboard. When berthing such a vessel, the pilots pay extra attention to wind conditions and hydrodynamic effects.

Figure 2. Side-view of turning operation. (distance of berth to the ship is 50m)

2.3 *Passage plan*

Before entering port, a ship's master normally prepares a passage plan. It is the pilot's task to carefully steer the ship from the pilot station to the target berth, taking into account information on the local environment, local guidelines and rules, and so on. The pilot should be briefed on the ship's passage plan, and should make any necessary corrections. After taking port information into account and comparing the pilot's suggested plan with that initially developed on board, the pilot and master should agree an overall final plan early in the passage before the ship is committed. All parties should be aware that elements of the plan may change. During the berthing approach, the pilot follows the plan faithfully and performs the steerage. Thus during training, pilot trainees should imitate all such maneuvering and steerage using the SMS.

During the simulation, pilot trainees steer the ship parallel of the berth, perform a 200m, turn of the ship in front of F quay and complete the ship berthing. The trainer uses the main engine, the rudder, two tugboats, and a bow thruster for steerage. (Ref. Figure 1, 2 and 3)

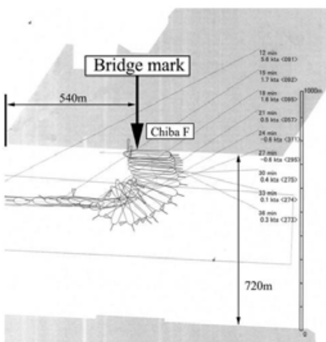

Table of Passage plan

(1) Ship's particular	
Kind of ship	PCC (Pure Car Carrier)
Gross Tonnage	58,000 ton
Deadweight	22,000 ton
Displacement	30,030 ton
Length Overall	199.93 m
Breadth	32.26 m
Draft fore	8.5 m
Draft aft.	8.5 m
Bow power	17.8 ton
(2) Assistance	
Tug Boat	3,500 HP X 2
(3) Memorandum of passage plan	
Depth	12.0 m
Bridge mark	Bridge position of objective quay
Keep lateral distance form berth	200m(1 L)
Target position	Objective turning point off Bridge mark 200m(1 L)

Figure 3. Typical passage plan .(berthing)

3 EVALUATION METHOD

3.1 *Pattern realization*

This scenario is intended to train a pilot's judgment based on information from many inputs. However, when trainees made a mistake the instructions offered for the required corrections were vague.

The experienced pilot monitors a large amount of information on the ship's position and speed, as well as the effects of wind and tugboats thrust, while maneuvering the vessel into berthing position. The pilot is able to control the ship by recognizing this enormous amount of information as a pattern. The experienced pilot has learned methods of pattern recognition and processing from his experience. In this sense a harbor pilot is similar to an aircraft pilot. The air pilot judges the state of the aircraft through constant monitoring of dozens of instruments, operates the plane's controls, and confirms that the craft is responding to his instructions. An aircraft pilot does not need to take the time to confirm individual information inputs; he instead steers by pattern recognition.

3.2 *MTS method*

The MTS method is a technique from the field of the quality engineering. It defines a person's action as a state and sets a normal area (NA) based on the expected normal range of that action. The index describing the standard state is in the normal area, while an index value outside the normal area is in an abnormal state. The degree to which the state is abnormal can be expressed as the distance from standard space. With this in mind, the authors define this distance as the Discrete Distance (DD), as shown in Figure 4.

The first step in performing MTS analysis is to define a "normal" group as the normal area. The normal group is selected with discretion to define a reference point on a measurement scale. Defining the normal group is a critical step in this method, since the NA is the reference point and basis of the measurement scale. An abnormal state or condition will lie outside of the normal group. The degree of abnormality is measured in reference to the normal group.

A threshold value of the index can be established to split the group of all states into two groups, with those values inside the threshold group being normal and those outside defined as abnormal. The threshold may be set empirically, based on statistical analysis of past data, and/or may be decided based on technical judgment.

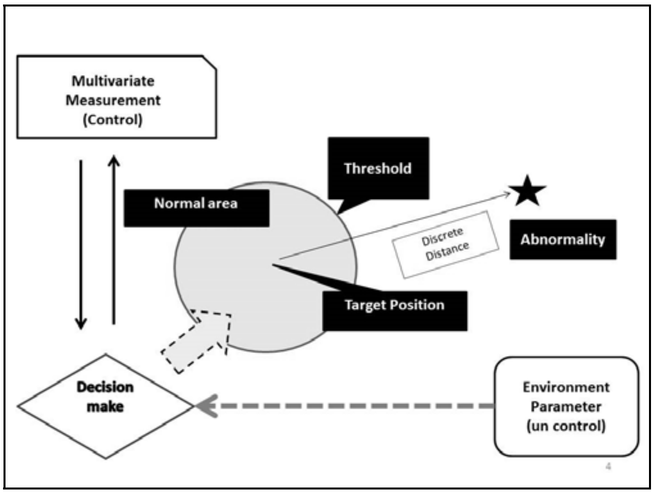

Figure 4. Pattern realization.

3.3 *Turning experiment*

As a specific case for study, the authors examined the simulation training exercise of turning a vessel 180 degrees in place using one tugboat. The maneuver was examined to establish the threshold of the SMS normal area. The ship's depth and position were measured during the ship's movement, and the position data are shown in Figure 6. The authors carried out this experiment at simulated initial speeds from zero to 3 knots; higher speeds were not investigated because of the difficulty in applying tugboat thrust at these speeds.

The authors selected the lateral distance of the bow movement when the ship turned at initial speed 2 knots to be the threshold value of the standard turning (Ref. Table 2).

Table 1. Ship information for the experiment.

Ship type	PCC (Pure Car Carrier)	
International Gross ton	58,000	ton
Dead Weight	22,000	ton
Displacement	30,030	ton
LOA	199.93	m
Breadth	32.26	m
Draft Fore	8.50	m
Draft Aft	8.50	m
Bow Thruster one	17.8	ton
Depth	12.0	m
H/d	1.4	

Table 2. Results of turning experiment.

Init. Speed (kts)	X (m)	Y (m)	Bow (Xm)
0.0	255.30	278.30	-43.80
1.0	128.20	344.20	-75.00
2.0	-9.70	377.70	-112.50
3.0	-138.30	386.90	-190.60

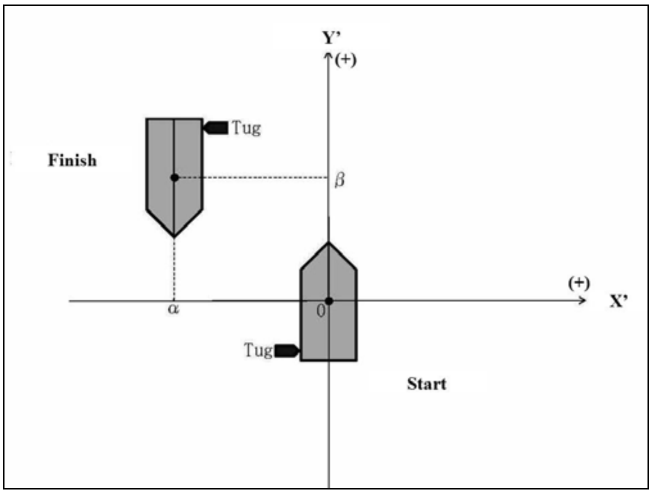

Figure 5. Diagram of the turning experiment.

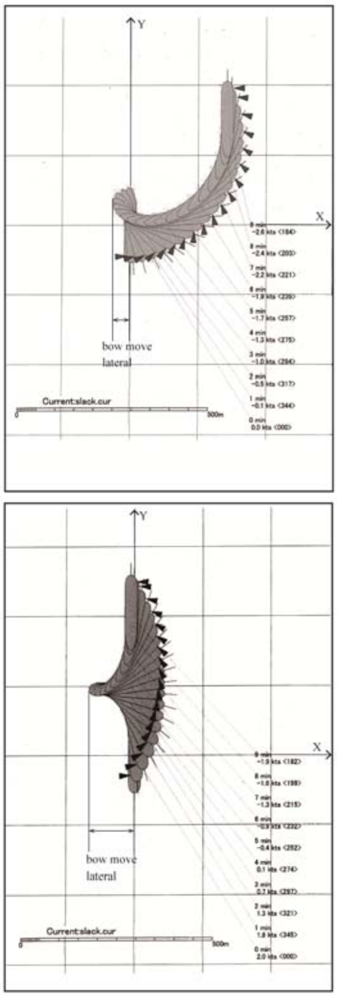

Figure 6. Positions during turn with initial speeds 0kts and 2kts.

3.4 *Index standard by this scenario*

The purpose of this training scenario is to acquire the technique of turning the vessel, controlling its speed and position as it turns anti-clockwise and is docked alongside the target quay. Therefore the authors measured the position (the position that had a bow for 90 degrees turned), and calculated the straight-line distance between the bow and the target position.

This distance was defined as the Discrete Distance (DD).

The threshold value of this distance, which defined the normal area of this parameter, assumed it to be 112.5m. In this paper we transform all lengths to the dimensionless unit L by normalizing them to the ship's length overall (LOA), making this value 0.56L. (Based on an experiment to mention at 3.3)

3.5 *Verification of Threshold*

The selected threshold splits the group of distance values into two parts, comprising those inside the threshold group ("normal") and outside ("abnormal"). The authors considered whether this threshold was proper using the results of simulator training with the same scenario from 2009 and 2008.

These data were based on four demonstrations of model steerage by the instructor, and 13 attempts by trainees who carried out this scenario using the SMS.

Table 3 gives the results from carrying out the scenario using SMS. For each SMS run, the position of the simulated ship's bow was determined in longitude(X) and latitude (Y) coordinates, and the bow's distance from the target position was calculated along each coordinate axis. These distances, given in dimensionless units L, area shown in Table 3 and plotted in Figure 7. The points labeled "Ins" are the instructor's model steerage.

Table 3. Deviations of bow positions and Discrete Distances from Target position for 17 SMS simulations runs.
Values of Discrete Distance in the normal area are shown in reversed shading (threshold 0.56L).

Class	No.	Long. X (L)	Lat. Y (L)	Discrete Distance (L)
Ins	1	-0.30	0.05	0.30
Ins	2	0.05	-0.01	0.05
Ins	3	0.06	0.05	0.08
Ins	4	0.03	0.02	0.03
08	5	-0.51	-0.11	0.52
08	6	-0.70	-0.13	0.71
08	7	-1.20	-0.18	1.21
09	8	-0.80	-0.36	0.88
09	9	-0.79	-0.19	0.81
09	10	-0.60	-0.02	0.60
09	11	-0.43	0.01	0.43
09	12	-0.54	0.15	0.56
09	13	-0.36	-0.04	0.36
09	14	-0.39	-0.23	0.45
09	15	-0.36	-0.25	0.44
09	16	-0.13	-0.13	0.18
09	17	0.14	-0.19	0.24

As can be seen in these results, the position of the turning ship's bow was widely dispersed. This suggests that the combination of controlling the main engine and ship's rudder while under tugboats assist are difficult for pilot trainees to master. However, five trainees achieved DD values within the 0.56L threshold value. Since five of 13 values were within the normal area, a DD of 0.56L appears to be valid as a threshold value.

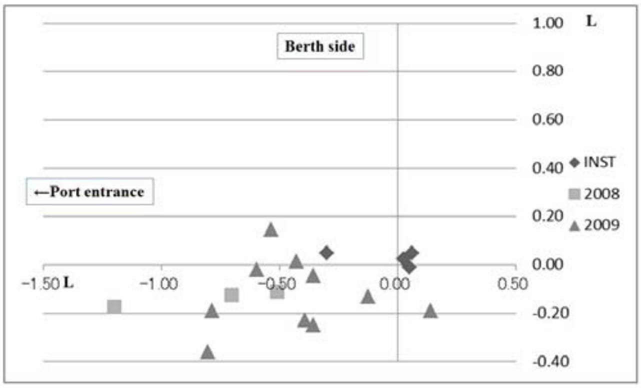

Figure 7. Scatter plot of the X- and Y-deviations of bow position from the target position for 17 SMS simulation runs.

4 EVALUATIONS

Figure 8 presents the results of simulator training of 51 trainees and their instructors. The data area plotted in the same fashion as Figure 7. The full data set is shown in Table 4, which includes values for the group mean and standard deviation for the X and Y deviations and the Discrete Distance. Among 51 simulator trials, 19(37.3%) produced final values of DD which were in the normal area.

The data in Table 8 indicate that the SMS berthing simulation is very challenging, even for those who area experienced masters of merchant ships. Defining the DD as the quality index for these training exercises explains this situation concretely. This index may be effective not only for assisting the instructor to provide concrete training assistance, but also in supporting peer assessment.

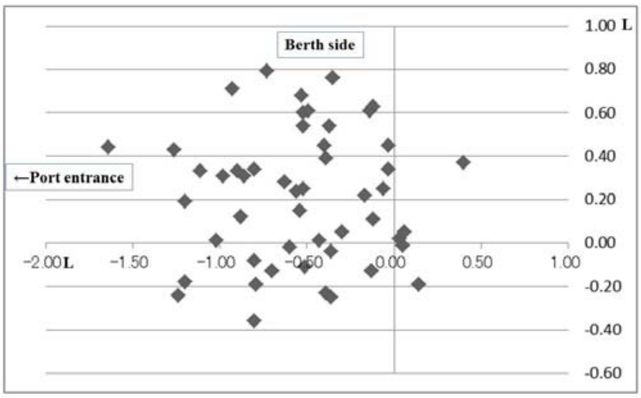

Figure 8. Results of evaluation.

Table 4. Deviations of bow positions and Discrete Distances from target position for 51 SMS simulation runs performed to evaluate DD as the quality index

No. (L)	Wind	X (L)	Y (L)	Discrete Distance
1		-0.30	0.05	0.30
2		0.05	-0.01	0.05
3		0.06	0.05	0.08
4	North	0.03	0.02	0.03
5		-0.52	0.25	0.58
6		-0.52	0.54	0.75
7		-0.93	0.71	1.17
8		-0.35	0.76	0.83
9		-0.39	0.39	0.55
10	South	-0.51	-0.11	0.52
11	South	-0.70	-0.13	0.71
12	South	-1.20	-0.18	1.21
13	South	-0.80	-0.36	0.88
14		-0.79	-0.19	0.81
15		-0.60	-0.02	0.60
16	North	-0.43	0.01	0.43
17	North	-0.54	0.15	0.56
18	North	-0.36	-0.04	0.36
19	South	-0.39	-0.23	0.45
20		-0.36	-0.25	0.44
21		-0.13	-0.13	0.18
22	North	0.14	-0.19	0.24
23		-0.12	0.63	0.64
24		-0.40	0.45	0.61
25		-0.03	0.34	0.34
26		-0.52	0.60	0.79
27		-1.26	0.43	1.33
28		-0.17	0.22	0.28
29		-0.37	0.54	0.66
30		-0.98	0.31	1.03
31		-1.24	-0.24	1.26
32	South	-0.03	0.45	0.46
33	North	-0.06	0.25	0.26
34	North	0.40	0.37	0.55
35	North	-0.12	0.11	0.16
36	North	-0.80	0.34	0.87
37	North	-0.80	-0.08	0.81
38		-0.63	0.28	0.69
39		-1.11	0.33	1.16
40	North	-0.88	0.12	0.89
41	South	-1.20	0.19	1.22
42	South	-0.49	0.61	0.78
43	North	-0.56	0.24	0.60
44		-0.90	0.33	0.96
45	North	-1.02	0.01	1.02
46		-0.53	0.68	0.86
47	North	-0.88	0.12	0.89
48		-1.64	0.44	1.70
49		-0.86	0.31	0.91
50		-0.73	0.79	1.08
51		-0.14	0.61	0.62
Average		-0.54	0.21	0.69
Standard Deviation		0.42	0.30	0.36

5 STATISTICS EVALUATION

5.1 *Lateral distance and approach speed*

Figure 9 and 10 show the lateral distance and vessel speeds at each of three evaluation spots, located. 1L, 2L and 3L from the target quay. The mean results of four simulation runs by an instructor were obtained and compared with the steerage of the trainees.

This comparison forms an evaluation index, following the technique described in previous studies

(Inoue 2010, 2011). The authors' statistical study revealed that the pilot trainees 1) took ample lateral distance in comparison with model steerage, and 2) tended to favor slow speed.

When instructors make a scenario for young pilot trainees without the captain's experience, they are able to make use of these statistical processing.

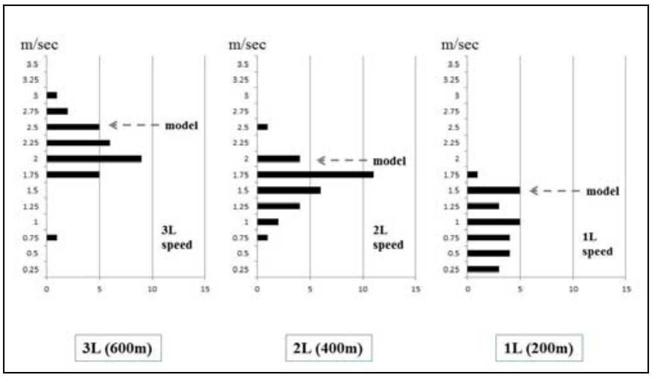

Figure 9. Histograms of modeled ship speed (m/sec) at the three evaluation positions.

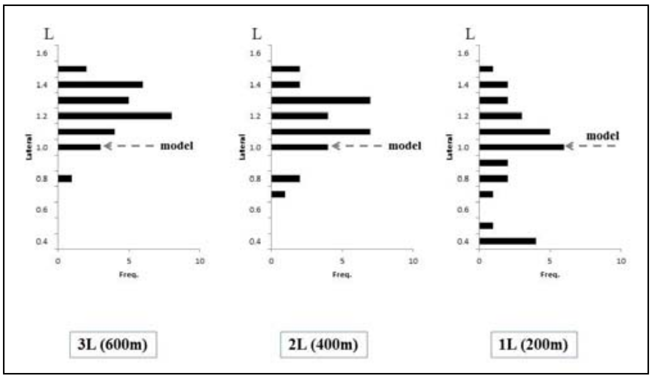

Figure 10. Histograms of lateral distance from the berth

Table 5. Model approach lateral distances and ship speeds. (Average)

Evaluation spot (m/sec)	Lateral distance (L)	Ship speed
1.0 L	1.03	1.50
2.0 L	1.08	2.10
3.0 L	1.12	2.60

Table 6. Model approach lateral distances and ship speeds. (Standard deviation)

Evaluation spot	Lateral distance (L)	Ship speed (m/sec)
1.0 L	0.07	0.20
2.0 L	0.09	0.30
3.0 L	0.09	0.30

5.2 *Figure of trail*

The "figure of trail" is a record of the moment to moment position of the vessel during the simulation. Because it is output promptly after each practice session, the figure of trail is an effective debriefing tool, helping to deepen the trainee's understanding of the instructor's evaluation.

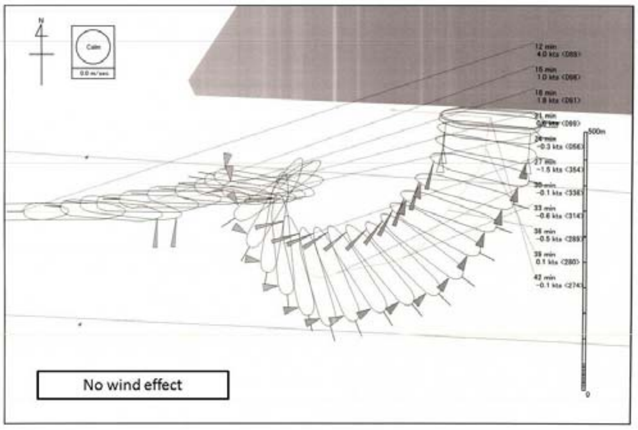

Figure 11. Figure of trail for Trainee No.48.

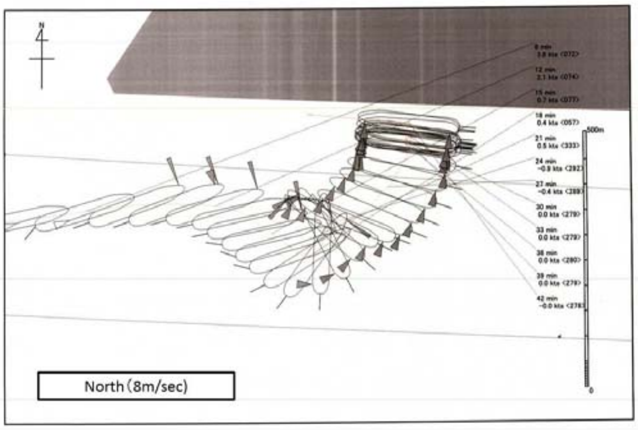

Figure 12. Figure of trail for Trainee No.47.

Figure 11 shows the trainee No.48. His DD was 1.7. Because the approach speed was slow, control of the ship was somewhat diminished, resulting in the turn being completed beyond the target turning position. The Instructor recommended additional training on the approach. Trainee No.47 maneuvered the ship under strong North wind. His DD was 0.89. When the speed of the ship declined as it closely approached the turning target, his ship had large leeway. The instructor taught him how to use the vertical thrust control of the ship. Because the instructor can understand the DD index immediately after practice, he can use the DD and the trail plot to explain any errors in a trainee's approach to the quay. The DD index was found to be effective as one of the parameters that can explain ship pilot's pattern recognition and their ability to control the ship while monitoring many inputs.

6 CONCLUSIONS

The authors propose a new method of evaluating maneuvering training harbor maneuvering using SMS. The method is based on defining an indicator, the discrete distance (DD), obtained from the ship's motion analysis after SMS training. Because it is easily measured from a figure of trail output, which is available promptly after the conclusion of the training exercise, the DD was found to effective for trainee evaluation. The study found that

– The instructor can review any mistakes made by the trainee during practice in terms of the concrete DD index;
– Other trainees easily understand DD in the evaluation between trainees, and are able to recognize those areas that require additional practice by the trainee;
– The instructor can evaluate the trainee's performance more practically using the DD index along with the speed and latitude distance at the approach evaluation spots;

Training data for this scenario generated by trainees who are already experienced ship masters can be statistically compiled to produce scenarios that will be effective for young trainees who do not yet have captain experience. These scenarios could help new trainees learn the following:
– The importance of maintaining approach speed and ample distance to the berth;
– The PCC is more vulnerable to wind at slow vessel speeds. As speed reduces, hydrodynamic forces reduce, and the effect of wind on heading and leeway increases.

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