Collaboration to Enhance Development and Application of Shiphandling Simulators

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Abstract

It has been well proved that shiphandling simulators are efficient and useful facilities for training and education of cadets and seafarers. Most of the maritime universities and many maritime training institutes all over the world have installed shiphandling simulators, which play important roles in maritime education and training. However, most of the Shiphandling simulators are standalone facilities with diversities on system architectures, layouts and functions. STCW78/95 requires simulators used for simulator-based training shall be suitable for the selected objectives and training tasks. To ensure the shiphandling simulator facilities meet the requirements of STCW convention and other expanded applications, collaborated research and coordination are needed in development and application of shiphandling simulators. Performance standard should be established for shiphandling simulator systems considering the advanced research needs as well as the needs in education, training, and assessment of competence. Standardizing and exchanging shiphandling mathematical models will improve critical performance of the system. Cooperated research on model course and training assessment approaches will enhance the training standard. In addition, the rapid spread of the internet technology has shown a promising future of application of shiphandling simulators through internet. Research has been carried out on internet based integration of multiple shiphandling simulators. A multi-agent based system, including necessary hardware, has been developed. Collaborated operation of the system can be of benefit in filling the gaps of the technical and operational level and methodology between maritime universities, enhancing mutual understanding of the navigation customs and culture background among cadets and seafarers from different countries, facilitating communication and maritime English training, and extending the functions of shiphandling simulators.

Keywords: shiphandling simulator, integration of systems, navigation simulation, maritime education and training

1. Introduction

Shiphandling simulator plays an important role in maritime industry. Because of high expense and risk for the shiphandling practice on real ship, shiphandling simulator training has been carried out in most maritime education and training (MET) institutions. Typical applications include handling of larger ships, training of bridge resource management [1] or bridge team management, as well as course related training programs such as standard maneuvering tests and collision avoidance scenarios. It is also found useful in maritime English practice for cadets to improve both on-board and external communication skills [2-3]. In recent years, shiphandling simulators have been increasingly used for port and waterway design [4]. Simulation assists the design and decision process by allowing alternative harbor and waterway designs to be examined without real risk and without the capital investment of implementing of an untested design. By allowing the examination of a variety of alternative designs, together with special combinations of ships, electronic aids, environmental conditions and operational practices, simulation can provide a design tailored as a special solution to the conditions in a specific port. The simulation process and the data analyses are of benefit for the design engineer to determine design berthing area and turning basin dimensions, outbound lane width, asymmetric or bended channel dimension, etc. It also helps the operator evaluate the effectiveness of navigation aids, determine the safe operational margins of environmental factors such as maximum wind force or current velocity. With the rapid expansion of road transportation, increasing number of bridges are built over important waterways, which may cause restrictions to navigation, difficulties of shipping and even collision accidents to both ship and bridge. Simulator assessments of safety of navigation have also be accepted as a valuable phase in bridge design and span configuration [5]. Simulator has also found its application in maritime accident analysis and maritime law suit consultation [6].

All these applications have a substantial impact on maritime safety and efficiency and are high-tech tasks, which require the simulators involved meet certain performance standards. Most of the navigation simulators nowadays, especially those in Asia, are designed and installed mainly for education and training purpose. Not all of them are suitable for the versatile applications. Internationally collaborated research and coordination are need in development and application of shiphandling simulators. Performance standard should be established for shiphandling simulator systems used for maritime education and training, and those used for other critical applications such as harbor and waterway design. Standardizing and exchanging shiphandling mathematical models will improve critical performance of the system. Cooperated research on model course and training assessment approaches will enhance the training standard. In addition, the rapid spread of the internet technology has shown a promising future of collaborated application of shiphandling simulators through internet.

2. Performance Standard

Shiphandling simulators installed in MET institutions differ in aspects such as configuration, hardware, software, and operational functions. Table 1 shows the simulator configuration in major MET institutions in China. Proper classification and regulation are necessary for proper application of the facilities.

Bridge simulators are usually classified into the following four categories,

- Full Mission: Capable of simulating a total environment, including capability for advanced maneuvering and pilotage training in restricted waterways.
- Multi Task: Capable of simulating a total navigation

environment, but excluding the capability for advanced restricted-water maneuvering.

- Limited Task: Capable of simulating an environment for limited (blind) navigation and collision avoidance training.
- Single Task: A desktop simulator utilizing computer graphics to simulate particular instruments, or to simulate a limited navigation/maneuvering environment but with the operator located outside (birds-eye view) the environment.

Table 1. Simulators in MET institutions in China

Name of institution		Description of configuration
Shanghai Maritime University	1	Primary Station: 120° Vision; 4 radar stations
	2	Primary Station: 120° Vision; 3 auxiliary stations with vision
Dalian Maritime University	1	Primary Station: 180° Vision; 1 auxiliary stations with vision
	2	Primary Station: 270° Vision; 3 auxiliary stations with vision
Wuhan University of Technology	1	Primary Station: 270° Vision; 3 auxiliary stations with vision
Jimei University	1	Primary Station: 180° Vision; 1 auxiliary stations with vision
Ninbo University	1	Primary Station: 270° Vision; 2 auxiliary stations with vision
Shanghai Fisheries University	1	Primary Station: 120° Vision; 2 radar station
Tianjin University of Technology	1	Primary Station: 120° Vision; 2 radar station
Zhanjiang Ocean University	1	Primary Station: 180° Vision; 2 auxiliary stations with vision
Nantong Vocational & Technical Shipping College	1	Primary Station: 170° Vision
Shanghai Maritime Technical College	1	Primary Station: 120° Vision; 4 radar station
Shanghai Ocean-shipping Education Center	1	Primary Station: 120° Vision; 4 radar station
Qindao Ocean Shipping Mariners College	1	Primary Station: 180° Vision; 2 auxiliary stations with vision
Ming Wah-SMU Shenzhen Continuation College	1	Primary Station: 120° Vision; 2 radar station
Education Center of China Changjiang National Shipping (Group) Corporation	1	Primary Station: 180° Vision
Zhoushan Maritime College	1	Primary Station: 90° Vision, 2 radar station

Based on this classification, Det Norske Veritas proposed a standard for bridge operation simulators [7]. The Maritime Safety Administration in China is preparing a national standard, *Shiphandling Simulator Technical Performance*, which classifies shiphandling simulators into three categories [8],

Class 1. *Class 1 shiphandling simulator should be applicable to basic level programs of maritime education, training and competency assessment.*

Class 2. *Class 2 shiphandling simulator should be applicable to basic level and intermediate level programs of maritime education, training and competency assessment.*

Class 3. *Class 3 shiphandling simulator should be applicable to basic level, intermediate level and high level programs of maritime education, training and competency assessment.*

The Basic level programs include ([9] A-II/1),

- Plan and conduct a passage and determine position
- Maintain a safe navigational watch
- Use of radar and ARPA to maintain safety of navigation
- Respond to emergencies
- Respond to a distress signal at sea
- Maneuver the ship

The intermediate level programs include ([9] A-II/2),

- Plan a voyage and conduct navigation
- Determine position and the accuracy of resultant position fix by any means
- Determine and allow compass errors
- Co-ordinate search and rescue operation
- Establish watchkeeping arrangements and procedures
- Maintain safe navigation through the use of radar and ARPA and modern navigation systems to assist command decision-making
- Maneuver and handle a ship in all conditions

The high level programs include,

- Bridge team management
- Bridge resource management
- Other composite tasks of maritime education, training and competency assessment.
- Requirements specified in STCW B-V/2
- Expandable for navigation areas and ship maneuvering models
- Expandable for other bridge facilities such as GMDSS, AIS, VDR, etc.

Figure 1. IBS simulator in Shanghai Maritime University

These standards are mainly proposed for maritime education and training. There are still two gaps need to be filled. (1) Lack of standards for research and advisory applications such as harbor and water way design, law suit application etc. (2) Needs of consideration of the innovation of bridge systems, since Integrated Bridge Systems (IBS) are increasingly popular on board modern ships, and new equipments, such as automatic identification systems (AIS), voyage data recorders (VDR), global maritime distress and safety systems (GMDSS), etc., become mandatory in ship bridges. Shanghai Maritime University has successfully developed an IBS simulator based on a real bridge system (Figure 1). IMO has also developed a model course, *Operational Use of Integrated Bridge Systems Including Integrated Navigation Systems* [12], for IBS training. It has been recognized that the safe and efficient use of integrated bridge systems and integrated navigation systems (INS) requires a level of knowledge beyond that normally given in the training of an officer in charge of a navigational watch. It is not just a matter of learning to use new controls, display techniques or how to switch on and off automatic functions. More importantly, it is learning the decision making processes that must be applied in order to gain the full benefits of the integration in a safe manner and avoid the new problems that automatic controls and integrated systems can sometimes provoke. We need global collaboration to meet these new challenges.

3. Mathematical Ship Maneuvering Model

The kernel of the shiphandling simulator is the hydrodynamic model used to calculate ship response to the variety of forces being exerted upon the vessel. Forces causing ship motion are both environmental and mariner controlled. Environmental forces are caused by wind, current, bank effects, shallow water, ship interaction, and waves. Mariner controlled forces are the results of rudder angle, propeller revolution, tugs, and bow and stern thrusters, lines and anchors. These forces cause six degrees of ship motion: three degrees of horizontal motion (surge, sway, and yaw) and three degrees of vertical motion (heave, pitch, and roll). It is impractical to take all these motions into account. Many navigation simulations are conducted using only the three degrees of horizontal motion. One of the effective mathematical models for shiphandling simulators is described by Equation (1–3).

$$m(\dot{u} - vr - X_G r^2) = X \qquad (1)$$

$$m(\dot{v} + ur + X_G \dot{r}^2) = Y \qquad (2)$$

$$I_z \dot{r} + mX_G(\dot{v} + ur) = N \qquad (3)$$

Where m = mass of the vessel

I_z = moment of inertia about z-axis

u = velocity of forward or astern motion

v = velocity of sideways motion

r = turning rate of the ship's heading

X = summation of forces along the longitudinal axis

Y = summation of forces along the lateral axis

N = summation of moments about the vertical axis

X_G = position of gravity center on x-axis

This type of model is based on the forces acting on the ship. It is convenient to include all contributing factors to the ship movement as long as it can be represented in terms of forces. In order to calculate the forces, variety of coefficients must be determined. Take a popular employed model, MMG ship maneuvering model, as an example, the right sides of Equation (1-3) are expanded as follows,

$$\begin{aligned} X &= X_{\dot{u}}\dot{u} + X_{vr}vr + [X_{vv} + X_{vv\eta}(\eta-1)]v^2 \\ &\quad + [X_{rr} + X_{rr\eta}(\eta-1)]r^2 + [X_{\delta\delta} + X_{\delta\delta\eta}(\eta-1)]\delta^2 \\ &\quad - (\text{Resistance}) + (\text{Thrust}) \end{aligned} \qquad (4)$$

$$\begin{aligned} Y &= Y_o + Y_{o\eta}(\eta-1) + Y_{\dot{v}}\dot{v} + Y_{\dot{r}}\dot{r} + [Y_v + Y_{v\eta}(\eta-1)]v \\ &\quad + [Y_r + Y_{r\eta}(\eta-1)]r + [Y_{v|v|} + Y_{v|v|\eta}(\eta-1)]v|v| \\ &\quad + [Y_{r|r|} + Y_{r|r|\eta}(\eta-1)]r|r| + Y_{vrr}vr^2 + Y_{r|v|}r|v| \\ &\quad + [Y_\delta + Y_{\delta\eta}(\eta-1)]\delta + Y_{\delta|\delta|}\delta|\delta| + Y_{\delta vv}\delta v^2 \end{aligned} \qquad (5)$$

$$\begin{aligned} N &= N_o + N_{o\eta}(\eta-1) + N_{\dot{v}}\dot{v} + N_{\dot{r}}\dot{r} + [N_v + N_{v\eta}(\eta-1)]v \\ &\quad + [N_r + N_{r\eta}(\eta-1)]r + [N_{v|v|} + N_{v|v|\eta}(\eta-1)]v|v| \\ &\quad + [N_{r|r|} + N_{r|r|\eta}(\eta-1)]r|r| + N_{vrr}vr^2 + N_{r|v|}r|v| \\ &\quad + [N_\delta + N_{\delta\eta}(\eta-1)]\delta + N_{\delta|\delta|}\delta|\delta| + N_{\delta vv}\delta v^2 \end{aligned} \qquad (6)$$

No need to explain the meaning of all the parameters in the equations. The interested readers are referred to [10]. It can be seen there are quite many parameters involved. Determination of those parameters is by no means trifle work, and may involve complicated captive model and full-scale tests as well as theoretical deductions. To solve ship motion equations in full is also time-consuming and real-time implementation of the model turn out to be difficult. Different approaches have been proposed to simplify the implementation, and Sutulo et al [11] suggested one of the versions,

- The effect of accompanying roll motion is in most cases weak and can be easily sacrificed. Thus, the equation of roll was omitted.
- The engine-and-propeller inertia is much lower than that of the ship itself and it can be supposed that the propeller rotation rate *n* can be changed instantly.
- An integrated polynomial regression model for the complex hull–rudder sway and yaw forces can be used instead of more complicated separate models. The model can be further simplified by eliminating some secondary-importance terms.
- A suitable mathematical model for longitudinal forces can be created with highly simplified representations for ship resistance and for the surge force induced by the rudder.
- The steering gear dynamics can be also neglected in many cases.

This kind of schedules may work well for path prediction. For simulation applications, however, we need roll and pitch motion, propeller and steering gear dynamics to ensure realistic 'feelings'. Furthermore, in shiphandling simulator context, the effects of wind, wave and current, shallow water and bank effects, and interaction with other ships should be well taken into account. Developing a general model suitable for ship maneuvering simulation remains an open problem. Collaboration is needed to develop and regulate ship motion models for shiphandling simulators. General accepted models are of significant for standardization of simulator operation and performance assessment. Only with them can exchange of model parameters and sharing of hydrodynamic test results of real or model ship be meaningful.

Another issue needs consideration is building some *virtual ship* models, which critically meet the IMO standards for ship maneuverability [16]. Those models are useful in navigation simulations for channel and waterway design. They provide kind of ships with "worse maneuverability", which nevertheless meet the criteria of the standard, to test rationality of the designs [4].

4. Model Courses and Training Assessment

It is well observed that the training method and syllabus differ quite much in each MET institution over the world. There is no common guideline of training method to all MET institutions. The only shiphandling simulator related IMO model course, *Ship Simulator and Bridge Teamwork* [13], presents some guidelines of simulator-based exercises. However, it is not specific enough for individual training program such as larger shiphandling or bridge resource management (BRM) training.

Take BRM as an example. Under the same name of the course, the contents are kinds of versatile and may focus on different aspects of maritime operation. Therefore, the same "BRM" certificates from different training programs may mean quite differently. The course of SAS Flight includes the flowing 12 modules, which concentrated on human factors [14],

- Attitude and management skills
- Cultural awareness
- Communications and briefings
- Challenge and response

- Short term strategy
- Authority and assertiveness
- Management styles
- Workload
- State of the bridge
- Human involvement in error
- Judgment and decision making
- Emergencies and leadership.

And some other course may be more technically oriented and includes,

- Basic principle
- Collision avoidance
- Pilot on the bridge, role authority and responsibility
- Bridge checklist
- Communication and briefing
- Standard maneuvers
- Wind and current effects
- Bank channel and interaction effect
- Passage planning
- Crisis and crowd management

In Shanghai Maritime University, our course may look like something in between, and concentrated in the flowing three aspects [1],

- *Operator's status*, which include how we behave, how we remember, how we perceive and process information, effects of fatigue, and effects of stress.
- *Communication skills*, which include understanding culture differences, situational awareness, close loop communication, briefing and debriefing, communication procedures and VTS communications.
- *Management skills*, which include bridge organization, error trapping, passage planning, decision making, motivating individuals, leadership, teamwork including pilot/master relationship, and emergency procedures.

Collaboration is needed to develop global syllabi or model courses for common training programs, such as larger shiphandling, bridge resource management, watchkeeping and collision avoidance, etc.

Besides standardization of training method, another problem is the accompanying assessment system to evaluate skill improvement of trainees. Although efforts to this issue have been continuously made, the problem is by no means satisfactorily solved. Quantitative assessment model should be developed for evaluating skill progress or improvement of trainees without instructors' subjectivity. With standardization of the training syllabi and methods, standardization of assessment measures is of significant in keeping the standard of training.

5. Internet Based Integration of Multiple Shiphandling Simulators

With the development of the technology in recent years, shiphandling simulator has been improved greatly on functional performance and scene image. However, most of the shiphandling simulators are standalone facilities and the trainees in the training programs usually come from the same country or the same company, which differs from the real situation. Navigation is an international activity, and there may be many ships from different countries sailing in the same sea area. There are some training institutes having seafarers from different countries or regions trained together as a team. This method proves to be costly. Integrating shiphandling simulators internationally through Internet is an effective way to solve the problem. On integrated shiphandling simulators, cadets and seafarers trained on local shiphandling simulator can conduct shiphandling and communication practice together with trainees at shiphandling simulators in other countries or regions. The integrated training will set up more realistic and versatile scenario for the trainees and it can be performed effectively and economically.

Internationalization of shiphandling simulator training will enhance seafarers' technical and operational abilities effectively. Shi et al [15] report the design and realization of an internet based platform, which is referred to as SHSLinker, to integrate multiple shiphandling simulators. A multi-agent based system, including necessary hardware, has been developed. The system consists of a web server linker, local simulator agents and an internet based simulated VHF communication system. The web server linker manages and coordinates the integrated simulators in the system. It also displays the necessary information and provides general functions for monitoring and controlling the system running. The local simulator agent communicates with local simulator and the server linker. The simulated VHF system performs communication functions between simulators linked to the internet. Draft of relative technical protocols has also been composed for the integration interface and data exchange. Figure 1 shows the general architecture of the system.

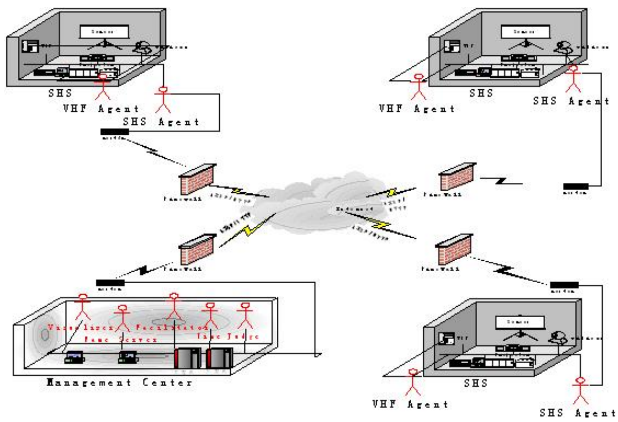

Figure 2. System architecture

Integrating multiple shiphandling simulators internationally is of benefit to the following expanded applications:

- To fill the gaps of the technical and operational level and methodology between maritime universities of the world. It is of benefit for global standardization of simulator training and promotes exchange and sharing of training experience
- To Enhance mutual understanding of the navigation customs and culture background among cadets and seafarers from different countries. It provides a good platform of intercommunion among cadets in an international background.
- To facilitate communication and Maritime English training. Through internet based VHF cadets and seafarers can communicate (using IMO Standard Marine Communication Phrases) in more realistic and diverse situations.
- To extend the application of shiphandling simulators. Integrated shiphandling simulators provides a good virtual environment for continuous watch-keeping practice in real time for a whole passage, 24 hrs a day on a watch shifting basis as on real voyage. And it is a good supplement to the training on real ships.

It is evident that implementing the integrated system will make the above mentioned collaboration indispensable, such as exchange of ship maneuvering mathematical models, exchange of course ware or training scenario settings, development of model courses, Setting up assessment standard and methodology, etc. Internet integration provides a new platform for collaboration and operation of shiphandling simulators.

6. Conclusions

To ensure the shiphandling simulator facilities meet the requirements of STCW convention and other expanded applications, collaborated research and coordination are needed in development and application of shiphandling simulators. Performance standard should be established for shiphandling simulator systems considering the advanced research needs as well as the needs in education, training, and assessment of competence. Standardizing and exchanging shiphandling mathematical models will improve critical performance of the system. Cooperated research on model course and training assessment approaches will enhance the training standard. In addition, the rapid spread of the internet technology has shown a promising future of application of shiphandling simulators through internet. Research has been carried out on internet based integration of multiple shiphandling simulators. A multi-agent based system, including necessary hardware, has been developed. Collaborated operation of the system can extend the functions of shiphandling simulators.

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