IMO-EU Joint Project: Capacity Building for Climate Mitigation in the Maritime Shipping Industry

Maritime Technology Cooperation Centre for Asia (MTCC-ASIA)

Uptake of Ship Energy Efficient Technologies and Operations

(Ship Trim Optimization)

Final Report

10 March 2020
Executive summary

The pilot project of uptake of ship energy efficient technologies and operations is one of most important components enshrined in the IMO-EU Joint Project: Capacity Building for Climate Mitigation in the Maritime Shipping Industry. The main contents including in this report are overall purpose and guiding principles of implementing this pilot project, 7-step procedure of project implementation, real ship data collection and analysis, equipment inventory, guideline and video development, track and feedback, database of demonstration ships and examples of visibility activities.

In order to legally and effectively achieve the overall purpose of this pilot project, MTCC-Asia utilizes the 7-step implementation procedure, i.e. seminar, on-hand system upgrade, data collection, data analysis, guideline and video development, track and feedback, and database of demonstration ships. As one of the main purposes of implementing this pilot project determined by MTCC-Asia is to validate the availability and reliability of the machine learning method to determine the ship optimum trim. Currently, total 63,569 of sets of ship data has been successfully collected from 15 demonstration ships (5 container ships, 5 bulk carriers and 5 oil tankers, respectively) by MTCC-Asia. The data quality indicates that the data collection method used by MTCC-Asia, i.e. collect data through manual input or electronic means and transmit data through satellite communication system is a reliable method that can be used in collecting the data for determining the ship optimum trim. The result of data analysis demonstrates that the method by using the machine learning principle is a reliable method to determine the ship optimum trim if the sufficient data is available. In addition, the result also proves that ship optimum trim operation is a reasonable and advantageous way to promote the ship energy efficiency. Less trim by bow the ship has less fuel the ship consumes, i.e. the ship will save more energy as it is trimmed by stem. If the optimum trim operation is adequately used on board, container ship and oil tanker can own nearly same fuel savings (5.66% and 5.73%, respectively), but both earn more fuel savings compared to bulk carrier (3.73%).

All of the outputs including the guideline (printed and electronic versions), quick guidance (printed and electronic versions), video, demo software of ship trim optimization based upon the machine learning method and a USB stick which stores all of these outputs are assembled by MTCC-Asia as a package and delivered to seafarers on board in order to share the outputs of this project with the shipping industry as much as possible.
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1. Implementation of pilot project

1.1 Overall purpose of implementing the pilot project

The overall purpose of implementing this pilot project determined by MTCC-Asia is to:

- promote the awareness of implementing the mandatory requirements on ship technical and operational measures for the uptake of energy efficiency;
- demonstrate the general effect of ship trim optimization on the given ship type;
- validate the availability and reliability of the machine learning method to determine the ship optimum trim; and
- facilitate the ships to effectively implement the mandatory requirements on ship technical and operational measures for the uptake of energy efficiency.

1.2 Procedure of implementing the pilot project

In order to legally and effectively achieve the overall purpose of this pilot project, as approved by the IMO PCU, MTCC-Asia utilizes the 7-step procedure which is wholly described with each step’s purpose in Figure 1.2-1. The implementation of each step is explained in details from Section 1.2.1 to 1.2.7.
Step 1: Seminar. To propagate the mandatory requirements on ship technical and operational energy efficiency, to formulate the guiding principles and to seek the support from the industry.

Step 2: On-hand system upgrade. To update the existing system in order to apply the machine learning method based on the sample dataset and to automatically and/or manually collect, transmit and process ship fuel oil consumption data, ship draft, speed and trim.

Step 3: Data collection. To obtain and store real ship fuel oil consumption data, ship draft, speed and trim from on board to on shore after installing the upgraded system on board.

Step 4: Data analysis. To analyze the data collected for demonstrating the general effect of ship trim optimization on the given ship and verifying the availability and reliability of machine learning method used.

Step 5: Guideline and video development. To develop a guideline and a video which presents the know-what and know-how on ship trim optimization and energy efficiency and distribute those to the ships.

Step 6: Track and feedback. To assess the effectiveness of guideline used on board for facilitating the industry to enforce the requirement.

Step 7: Database of ships using trim optimization. To collect the situation for the purpose of understanding the applicability of this operation.

Figure 1.2-1 7-step procedure of implementing the pilot project

1.2.1 Seminar

(1) General information of three seminars

In order to propagate the IMO’s mandatory requirements on ship fuel oil consumption data collection and to seek the intelligent and physical support from the shipping industry and maritime administration, MTCC-Asia has held three seminars related to ship fuel oil consumption data collection and reporting in June 2017, April 2018, March 2019 in Shanghai, respectively. All seminars were participated by 56 experts and professionals from maritime administrations and the shipping industry. The regulatory requirements, overall purpose of the pilot project, significant importance, existing practices and progress, difficulties and challenges encountered and forthcoming plan with regards to ship fuel oil consumption data collection were fully exchanged and deeply discussed.
(2) Guiding principles of implementing the pilot project

The ensuing views exchanged on the seminars were formulated by MTCC-Asia as the guiding principles of implementing the pilot project:

- The machine learning method used for determining ship optimum trim in principle is a reasonable and advantageous way to promote the ship energy efficiency under the condition of the compliance with the IMO’s mandatory requirements;

- The preferred machine learning method used for determining the ship optimum trim shall be a system which is able to automatically collect the data on board, transmit the data from on board to on shore;

- The system using machine learning method to determine the ship optimum trim shall be adequately validated before used on board as the effectiveness of machine learning method is highly dependent on the quantity and quality of training dataset;

- The system used in the pilot project shall be independently operated to avoid the unpredicted interruption to the existing system used on board;

- The demonstration ships selected shall be typically representative, considering the factors such as ship type, ship size, ship age, ship voyage, automation of facility and equipment on board;

- The same type of ship, in particular bulk carriers and oil tankers, shall be similarity-related in order that all data of this type of ships can be used together to avoid that the data collected from an individual ship is too less to not be used for the system training; and

- Ship data collected by the pilot project shall be confidentially kept anonymized and by no means can these data be published or reproduced without the written permission from the ship-owner in advance.

In addition, MTCC-Asia has also obtained the initial information from three shipping stakeholders who are willing to provide the demonstration ships to support the pilot project. Section 3.3 will introduce some details regarding the demonstration ships.

1.2.2 On-hand system upgrade

Based upon the guiding principles above-mentioned in Section 1.2.1, an existing system for ship trim optimization has been successfully updated and put into operation by MTCC-Asia.

(1) System function

This system is able to offer the following main functions:

- To provide the interface for automatically or manually inputting the ship’s
dynamic information regarding the ship trim optimization, at least including the information of:

➢ reporting date and time
➢ departure port
➢ destination port
➢ navigational status of underway
➢ speed over ground in knot
➢ fuel oil consumption in metric tonnes of main engine
➢ fuel oil type
➢ ship mean draft in meter
➢ ship trim in meter

- To store the data collected on shore and on board.

- To transmit the data collected from on board to on shore in real time through the specific communication equipment independent of the existing system used on board.

- To automatically determine ship optimum trim by using the machine learning algorithm based on the relevant data collected and compare the fuel savings.

Therefore, the logical functions of the system for ship trim optimization can be summarized as four aspects: data input, data storage, data transmission, data processing and illustrated in Figure 1.2.2-1.

![Figure 1.2.2-1 Logical functions of the system for ship trim optimization](image)

(2) System component
Following the logical functions of the system for ship trim optimization determined by MTCC-
Asia, this entire system is divided into three physical components: onboard application component, data transmission component and onshore application component, see Figure 1.2.2-2.

Onboard application component provides the user-friendly interface and enables operators to automatically or manually input the ship’s dynamic information regarding the determination of the ship trim optimization and store the data collected on board each ship. Figure 1.2.2-3 shows a snapshot of onboard application component.

Data transmission component is to transmit the data collected from on board to on shore in
real time. In order to ensure the system can be independently operated to avoid the unpredicted interruption to the existing system used on board and meanwhile the data can be transmitted in a reliable and efficient manner, MTCC-Asia selects the INMARSAT, BeiDou Navigation Satellite System (BDS) and Internet as the communication media between ship and shore for the ship fuel consumption data collection. In November 2014 the BDS has gained recognition from IMO. In comparison with other Global Navigation Satellite System, the BDS integrates navigation and short message communication capabilities. The BDS is currently able to provide the stable service within the Asia and Pacific region and it will be extended to the global by 2020 according to its development strategy. The obvious advantage by using the BDS for the ship fuel consumption data collection is that the ship can benefit from the independent communication channel, lower communication fee and simple installation of onboard terminal.

Onshore application component named as Ship Trim Optimization Management System is the central part of the entire system. Besides storing the data collected from all demonstration ships, it is able to automatically by using the machine learning algorithm determine ship optimum trim based on the relevant data collected and compare the fuel savings. Figure 1.2.2-4 shows a snapshot of onshore application component.

![Figure 1.2.2-4 Snapshot of onshore application component](image)

Ship Trim Optimization Management System is also promoted during the implementation of this project and distributed to ships as one of outputs of this project.

(3) Equipment inventory
The equipment used in this pilot project includes software and hardware. The inventory of those equipment and their pictures are listed in Table 1.2.2-1 as follows:
<table>
<thead>
<tr>
<th>Item</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onboard application component</td>
<td><img src="image1" alt="Picture" /></td>
</tr>
<tr>
<td>Onshore application component</td>
<td><img src="image2" alt="Picture" /></td>
</tr>
<tr>
<td>BeiDou message combination terminal</td>
<td><img src="image3" alt="Picture" /></td>
</tr>
<tr>
<td>BeiDou message SIM card</td>
<td><img src="image4" alt="Picture" /></td>
</tr>
<tr>
<td>BeiDou message terminal holder</td>
<td><img src="image5" alt="Picture" /></td>
</tr>
<tr>
<td>Item</td>
<td>Image</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>BeiDou message terminal hoop</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>BeiDou message terminal antenna cable</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>BeiDou message terminal USB cable</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>BeiDou message terminal power adapter</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Monitor of onboard application system</td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
</tbody>
</table>
1.2.3 Data collection

The total 63,569 of sets of data for determining the ship optimum trim in total has been successfully collected from 15 demonstration ships by MTCC-Asia after installing the system developed on board. The detailed information of data collected for each demonstration ship is presented in Section 2 Data collection.

1.2.4 Data analysis

To validate the availability and reliability of the machine learning method for determining the ship optimum trim, the data collected is analyzed which is introduced in Section 3 Data analysis.

1.2.5 Guideline and video development

MTCC-Asia developed and published the Guidelines on Ship Trim Optimization based on the Machine Learning Method and its corresponding quick guidance and video which presents the know-what and know-how on improving ship energy efficiency using ship trim optimization based on the machine learning method and distributed those to the ships. The details of the guideline, quick guidance and video are included in Section 4 Guideline and video development.
1.2.6 Track and feedback

The step is to collect the comments and feedback to the draft guidelines and relevant demo software of ship trim optimization from the demonstration ships and experts in order to update these outputs. This step also includes collecting the feedback from the shipping industry after the finalized outputs are circulated and evaluating the effectiveness based on the collected feedback. The details of track and feedback are included in Section 5 Track and feedback.

1.2.7 Database of ships using trim optimization

The step is to collect the number of ships using trim optimization for the purpose of understanding how ships are interested in this operation. The details of database of ships using trim optimization are included in Section 6 Database of ships using trim optimization.

1.3 Demonstration ships

Following the guiding principles that the demonstration ships selected shall be typically representative, considering the factors such as ship type, ship size, ship age, ship voyage, automation of facility and equipment on board, MTCC-Asia has successfully chosen 15 sea-going vessels, 5 container ships, 5 bulk carriers and 5 oil tankers as the demonstration ships of this pilot project under the generous support from three stakeholders.

5 container ships are serving the cross-continental trade between Asia and Europe, representing the newly-built ships with the average gross tonnage 122,321, length overall 336 meters, service speed 23 knots and age of 3.8 years. Compared to other types of demonstration ships, these container ships have a relatively high automatic facility and equipment installed on board. For instance, the flowmeters and the corresponding electronic supportive system are installed on these 5 container ships, which in principle provides the alternative to collect ship fuel consumption data with more frequent and accurate.

5 oil tankers represent the moderately-built ships serving the voyage within the Asian region with the average gross tonnage 635,88, length overall 234 meters, service speed 14.6 knots and age of 9 years.

And 5 bulk carriers are relatively old ships, averagely aged in 20.2 years and engaging on the coastal voyage at present. The average gross tonnage 439,71, length overall 229 meters and service speed 14.2 knots. Both oil tankers and bulk carriers are lack of electronic facility and equipment for recording ship fuel oil consumption data on board, which signifies that ship fuel consumption data can be collected in a manual and daily manner.

2. Data collection

2.1 Container ship

With regard to this pilot project, currently the total 60,666 sets of data related to determining
the ship optimum trim have been successfully collected from 5 demonstration container ships when they are underway. The general information of data collection for 5 demonstration container ships is shown in Table 2.1-1. The number of data collected is not evenly distributed within 5 container ships due to the difference of data collection duration and the availability of ship.

Table 2.1-1 General information of data collection for 5 container ships

<table>
<thead>
<tr>
<th>No.</th>
<th>Ship</th>
<th>Start date</th>
<th>End date</th>
<th>Data number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Container ship A</td>
<td>2017/9/14 11:30</td>
<td>2018/9/8 21:30</td>
<td>25152</td>
</tr>
<tr>
<td>4</td>
<td>Container ship B</td>
<td>2018/5/22 4:00</td>
<td>2019/4/28 12:45</td>
<td>5233</td>
</tr>
<tr>
<td>2</td>
<td>Container ship C</td>
<td>2017/6/7 2:00</td>
<td>2019/5/7 21:00</td>
<td>10220</td>
</tr>
<tr>
<td>5</td>
<td>Container ship D</td>
<td>2018/1/3 5:30</td>
<td>2019/1/6 14:00</td>
<td>11563</td>
</tr>
<tr>
<td>3</td>
<td>Container ship E</td>
<td>2017/7/29 16:15</td>
<td>2017/12/17 16:30</td>
<td>8498</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td></td>
<td></td>
<td>60666</td>
</tr>
</tbody>
</table>

Each set of data includes 7 information field: data and time, status, speed, fuel consumption of main engine, fuel type of main engine, mean draft and trim. As the flowmeters and draft measuring sensors and their supportive electronic system are installed and working in normal conditions on 5 container ships board, the data collected on these ships board can be with more frequent (every 15 minutes) and more accurate in an automatic manner compared to the data collected from below oil tankers and bulk carrier. Figure 2.1-1 shows the example of dataset collected on container ships.
Figure 2.1-1 Example of dataset collected on container ships

2.2 Bulk carrier

With regard to this pilot project, currently the total 1,458 sets of data related to ship fuel oil consumption have been successfully collected from 5 demonstration bulk carriers when they are underway. The general information of data collection for 5 demonstration bulk carriers is shown in Table 2.2-1.

Table 2.2-1 General information of data collection for 5 bulk carriers

<table>
<thead>
<tr>
<th>No.</th>
<th>Ship</th>
<th>Start date</th>
<th>End date</th>
<th>Data number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bulk carrier A</td>
<td>2018/2/1 0:00</td>
<td>2019/1/31 12:00</td>
<td>338</td>
</tr>
<tr>
<td>2</td>
<td>Bulk carrier B</td>
<td>2018/2/1 0:00</td>
<td>2019/1/31 12:00</td>
<td>364</td>
</tr>
<tr>
<td>3</td>
<td>Bulk carrier C</td>
<td>2018/2/1 0:00</td>
<td>2019/1/31 12:00</td>
<td>160</td>
</tr>
<tr>
<td>4</td>
<td>Bulk carrier D</td>
<td>2018/2/2 0:00</td>
<td>2019/1/31 12:00</td>
<td>312</td>
</tr>
<tr>
<td>5</td>
<td>Bulk carrier E</td>
<td>2018/2/10 0:00</td>
<td>2019/1/31 12:00</td>
<td>284</td>
</tr>
</tbody>
</table>

|            | Sub-total    | 1458            |

Likewise, each set of data includes 7 information field: data and time, status, speed, fuel consumption of main engine, fuel type of main engine, mean draft and trim. As the flowmeters and draft measuring sensors and their supportive electronic system are not installed on 5 bulk carriers board, the data collected on these ships board can only be collected by seafarers on board in daily interval and transmitted from ship to shore via the
system developed by MTCC-Asia. Figure 2.2-1 shows the example of dataset collected on bulk carriers.

![Figure 2.2-1 Example of dataset collected on bulk carriers](image)

### 2.3 Oil tanker

With regard to this pilot project, currently the total 1,445 sets of data related to ship fuel oil consumption have been successfully collected from 5 demonstration oil tankers when they are underway. The general information of data collection for 5 demonstration oil tankers is shown in Table 2.3-1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Ship</th>
<th>Start date</th>
<th>End date</th>
<th>Data number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oil tanker A</td>
<td>2017/5/18 12:00</td>
<td>2018/5/8 12:00</td>
<td>292</td>
</tr>
<tr>
<td>2</td>
<td>Oil tanker B</td>
<td>2017/5/13 12:00</td>
<td>2018/5/5 12:00</td>
<td>298</td>
</tr>
<tr>
<td>3</td>
<td>Oil tanker E</td>
<td>2017/5/5 12:00</td>
<td>2018/5/10 12:00</td>
<td>370</td>
</tr>
<tr>
<td>4</td>
<td>Oil tanker D</td>
<td>2017/6/5 12:00</td>
<td>2018/5/5 12:00</td>
<td>232</td>
</tr>
<tr>
<td>5</td>
<td>Oil tanker E</td>
<td>2017/5/28 12:00</td>
<td>2018/5/9 12:00</td>
<td>253</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td></td>
<td></td>
<td>1445</td>
</tr>
</tbody>
</table>

Likewise, each set of data includes 7 information field: data and time, status, speed, fuel consumption of main engine, fuel type of main engine, mean draft and trim. As the flowmeters and draft measuring sensors and their supportive electronic system are not
installed on 5 oil tankers board, the data collected on these ships board can only be collected by seafarers after they use bunker fuel oil tank monitoring on board in daily interval and transmitted from ship to shore via the system developed by MTCC-Asia. Figure 2.3-1 shows the example of dataset collected on oil tankers by bunker fuel oil tank monitoring on board.

<table>
<thead>
<tr>
<th>No.</th>
<th>Date and time</th>
<th>Status</th>
<th>Hours</th>
<th>Distance (nm)</th>
<th>Speed (kt)</th>
<th>Fuel cons.</th>
<th>Main engine</th>
<th>Draft mean (m)</th>
<th>Trim (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2017/5/5</td>
<td>Underway</td>
<td>18</td>
<td>242</td>
<td>13.3</td>
<td>17.9</td>
<td>HFO</td>
<td>11.8</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>2017/5/6</td>
<td>Underway</td>
<td>24</td>
<td>276</td>
<td>11.5</td>
<td>23.1</td>
<td>HFO</td>
<td>12.6</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>2017/5/7</td>
<td>Underway</td>
<td>21</td>
<td>212</td>
<td>9.7</td>
<td>17.8</td>
<td>HFO</td>
<td>12.2</td>
<td>0.3</td>
</tr>
<tr>
<td>4</td>
<td>2017/5/8</td>
<td>Underway</td>
<td>3</td>
<td>28</td>
<td>7.8</td>
<td>3</td>
<td>HFO</td>
<td>12</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>2017/5/10</td>
<td>Underway</td>
<td>15</td>
<td>178</td>
<td>11.3</td>
<td>15.5</td>
<td>HFO</td>
<td>12.8</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
<td>2017/5/11</td>
<td>Underway</td>
<td>7</td>
<td>7</td>
<td>10.1</td>
<td>8.5</td>
<td>HFO</td>
<td>12.1</td>
<td>0.6</td>
</tr>
<tr>
<td>7</td>
<td>2017/5/15</td>
<td>Underway</td>
<td>2</td>
<td>28</td>
<td>14.2</td>
<td>4.2</td>
<td>HFO</td>
<td>13</td>
<td>0.1</td>
</tr>
<tr>
<td>8</td>
<td>2017/5/16</td>
<td>Underway</td>
<td>7</td>
<td>81</td>
<td>11.1</td>
<td>10.6</td>
<td>HFO</td>
<td>12.8</td>
<td>0.1</td>
</tr>
<tr>
<td>9</td>
<td>2017/5/17</td>
<td>Underway</td>
<td>4</td>
<td>40</td>
<td>10</td>
<td>5.2</td>
<td>HFO</td>
<td>12.7</td>
<td>0.8</td>
</tr>
<tr>
<td>10</td>
<td>2017/5/19</td>
<td>Underway</td>
<td>3</td>
<td>9</td>
<td>0.1</td>
<td>4.4</td>
<td>HFO</td>
<td>11.3</td>
<td>1.1</td>
</tr>
<tr>
<td>11</td>
<td>2017/5/20</td>
<td>Underway</td>
<td>24</td>
<td>304</td>
<td>12.7</td>
<td>26.6</td>
<td>HFO</td>
<td>11.8</td>
<td>0.3</td>
</tr>
<tr>
<td>12</td>
<td>2017/5/21</td>
<td>Underway</td>
<td>24</td>
<td>288</td>
<td>12.2</td>
<td>27</td>
<td>HFO</td>
<td>12.5</td>
<td>0.4</td>
</tr>
<tr>
<td>13</td>
<td>2017/5/22</td>
<td>Underway</td>
<td>15</td>
<td>155</td>
<td>10</td>
<td>20.2</td>
<td>HFO</td>
<td>12.3</td>
<td>0.3</td>
</tr>
<tr>
<td>14</td>
<td>2017/5/26</td>
<td>Underway</td>
<td>6</td>
<td>60</td>
<td>9.9</td>
<td>9.7</td>
<td>HFO</td>
<td>13</td>
<td>0.2</td>
</tr>
<tr>
<td>15</td>
<td>2017/5/27</td>
<td>Underway</td>
<td>6</td>
<td>115</td>
<td>19.2</td>
<td>17.5</td>
<td>HFO</td>
<td>12.6</td>
<td>0.6</td>
</tr>
<tr>
<td>16</td>
<td>2017/5/29</td>
<td>Underway</td>
<td>5</td>
<td>55</td>
<td>10.3</td>
<td>9.5</td>
<td>HFO</td>
<td>12.7</td>
<td>0.7</td>
</tr>
<tr>
<td>17</td>
<td>2017/5/30</td>
<td>Underway</td>
<td>1</td>
<td>14</td>
<td>10</td>
<td>5.1</td>
<td>HFO</td>
<td>11.4</td>
<td>0.4</td>
</tr>
<tr>
<td>18</td>
<td>2017/5/31</td>
<td>Underway</td>
<td>24</td>
<td>180</td>
<td>7.5</td>
<td>15.7</td>
<td>HFO</td>
<td>12.4</td>
<td>0.5</td>
</tr>
<tr>
<td>19</td>
<td>2017/6/1</td>
<td>Underway</td>
<td>24</td>
<td>180</td>
<td>7.5</td>
<td>11.8</td>
<td>HFO</td>
<td>12.9</td>
<td>0.5</td>
</tr>
<tr>
<td>20</td>
<td>2017/6/2</td>
<td>Underway</td>
<td>24</td>
<td>144</td>
<td>6</td>
<td>14.9</td>
<td>HFO</td>
<td>11</td>
<td>1.1</td>
</tr>
<tr>
<td>21</td>
<td>2017/6/3</td>
<td>Underway</td>
<td>24</td>
<td>165</td>
<td>6.9</td>
<td>26.1</td>
<td>HFO</td>
<td>11.2</td>
<td>0.9</td>
</tr>
<tr>
<td>22</td>
<td>2017/6/4</td>
<td>Underway</td>
<td>24</td>
<td>204</td>
<td>12.7</td>
<td>30.5</td>
<td>HFO</td>
<td>12.7</td>
<td>0.2</td>
</tr>
<tr>
<td>23</td>
<td>2017/6/5</td>
<td>Underway</td>
<td>24</td>
<td>307</td>
<td>12.7</td>
<td>24.5</td>
<td>HFO</td>
<td>12.1</td>
<td>0.9</td>
</tr>
<tr>
<td>24</td>
<td>2017/6/6</td>
<td>Underway</td>
<td>2</td>
<td>30</td>
<td>10.9</td>
<td>6.8</td>
<td>HFO</td>
<td>11.1</td>
<td>0.3</td>
</tr>
<tr>
<td>25</td>
<td>2017/6/9</td>
<td>Underway</td>
<td>22</td>
<td>293</td>
<td>13</td>
<td>22.4</td>
<td>HFO</td>
<td>11.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Figure 2.3-1 Example of dataset collected on oil tankers

3. Data analysis

3.1 Container ships

3.1.1 Data pre-cleaning

As the data collected from demonstration container ships is based on the electronic system instead of manual input, some datasets collected shall be pre-cleaned due to the following reasons:

- Some crucial information such as fuel consumption, trim, mean draft or speed is missing;
- Some information is obviously against the physical rules and real operations; e.g. the draft is more than 30m or the trim is over 4m; and
- Some information obviously indicates that the ship is non-underway, e.g. fuel consumption per hundred nautical mile is over times of ship underway due to the frequent maneuverability during berthing or unberthing operations.
3.1.2 Determination of primary speed and primary draft

After data pre-cleaning, the primary speed and primary draft for each ship can be determined based on the histogram of the remaining dataset.

Figure 3.1.2-1 to Figure 3.1.2-5 show the speed histograms of 5 container ships, respectively, where data in horizontal axis means the ship’s speed and data in vertical axis means the quantity of ship’s speed.
Figure 3.1.2-3 Speed histogram of Container ship C

Figure 3.1.2-4 Speed histogram of Container ship D

Figure 3.1.2-5 Speed histogram of Container ship E

Figure 3.1.2-6 to Figure 3.1.2-10 show the draft histograms of 5 container ships, respectively.
Figure 3.1.2-6 Draft histogram of Container ship A

Figure 3.1.2-7 Draft histogram of Container ship B

Figure 3.1.2-8 Draft histogram of Container ship C
Figure 3.1.2-9 Draft histogram of Container ship D

Figure 3.1.2-10 Draft histogram of Container ship E

Therefore, the primary speed and primary draft for 5 container ships can be summarized in Table 3.1.2-1.

<table>
<thead>
<tr>
<th>Ship name</th>
<th>Pri. speed (V1)</th>
<th>Pri. speed (V2)</th>
<th>Pri. speed (V3)</th>
<th>Pri. draft (d1)</th>
<th>Pri. draft (d2)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container ship A</td>
<td>16.5-17.5</td>
<td>17.5-18.5</td>
<td>18.5-19.5</td>
<td>10.5-11.0</td>
<td>/</td>
<td>All 3 primary speeds are corresponded with primary draft d1.</td>
</tr>
<tr>
<td>Container ship B</td>
<td>14.0-15.0</td>
<td>16.0-17.0</td>
<td>17.0-18.0</td>
<td>14.0-14.5</td>
<td>15-15.5</td>
<td>Primary speeds V1 and V2 are corresponded with primary draft d1.</td>
</tr>
<tr>
<td>Container</td>
<td>15.5-16.5</td>
<td>16.5-17.5</td>
<td>18.5-19.5</td>
<td>13.0-14.0</td>
<td>/</td>
<td>All 3 primary</td>
</tr>
<tr>
<td>ship C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>speeds are corresponded with primary draft d1.</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>--------------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Container ship D</td>
<td>16.0-17.0</td>
<td>17.0-18.0</td>
<td>18.0-19v</td>
<td>12.0-13.2</td>
<td>/ All 3 primary speeds are corresponded with primary draft d1.</td>
<td></td>
</tr>
<tr>
<td>Container ship E</td>
<td>11.0-12.0</td>
<td>14.5-15.5</td>
<td>16.0-17.0</td>
<td>13.3-14.3</td>
<td>10.8-12.0 Primary speeds V1 and V2 are corresponded with primary draft d1.</td>
<td></td>
</tr>
</tbody>
</table>

### 3.1.3 Determination of optimum trim for container ship

Considering the range of primary speed and primary draft, the relationship between ship trim and fuel consumption for 5 container ships can be analyzed in Figure 3.1.3-1 (where horizontal axis and vertical axis represent trim and fuel consumption per hundred nautical mile).
Figure 3.1.3-1 Relationship between trim and fuel consumption at primary speed and draft for container ship

The lowest points of red lines in Figure 3.1.2-1 signify the least fuel consumption corresponding with the ship optimum trim at the primary speed and draft. It is hence concluded that except for the ship of Container ship E, the following rules are observed by container ships:
• At the constant draft, the least fuel consumption will reduce as the ship speed goes down; and
• At the constant draft, the trim corresponding with the least fuel consumption will gradually move to the left side as the speed decreases, which indicates that less trim by stern less fuel consumption, i.e. the ship will save more energy as it is trimmed by bow.

3.1.4 Fuel-saving analysis for container ship

Figure 3.1.4-1 shows the general relationship of ship primary speed, trim, draft and fuel consumption for Container ship A, where primary speed (16.5-17.5kn) is used, horizontal axis and vertical axis represent trim and draft, respectively, and the blue points mean the real dataset collected.

Therefore, from Figure 4.1.2-1, during the primary speed of 16.5-17.5kn, as it is underway at the 10.5m of draft, in principle the optimum trim of Container ship A is 0.75-0.8m corresponding with the least fuel consumption at 21t per hundred nautical mile (i.e. about 85t per day). However, based on the real data collected, the real fuel consumption per hundred nautical mile for Container ship A under the same conditions of draft and speed is about 22.3t, which indicates that when Container ship A draft is 10.5m and sailing at the speed of 16.5-17.5kn, it will save fuel about 1.3t, i.e. 5.83% if the optimum trim 0.75-0.8m is used.

Similarly, the general relationship of ship primary speed, trim, draft and fuel consumption for Container ship B, Container ship C, Container ship D and Container ship E can be shown in Figure 3.1.4-2, Figure 3.1.4-3, Figure 3.1.4-4 and Figure 3.1.4-5, respectively.
Figure 3.1.4-2 General relationship of ship primary speed, trim, draft and fuel consumption for Container ship B

Figure 3.1.4-3 General relationship of ship primary speed, trim, draft and fuel consumption for Container ship C
To sum up, the fuel energy-saving for 5 container ships when they use the optimum trims at the specific draft and primary speed can be summarized in Table 3.1.4-1.

Table 3.1.4-1 Fuel energy-saving for container ships

<table>
<thead>
<tr>
<th>Ship</th>
<th>Primary speed(kn)</th>
<th>Draft(m)</th>
<th>Optimum trim(m)</th>
<th>Fuel saving(t)</th>
<th>Fuel saving(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container ship A</td>
<td>16.5-17.5</td>
<td>10.5-11.0</td>
<td>-0.2-0.4</td>
<td>1.30</td>
<td>5.83</td>
</tr>
<tr>
<td>Container ship B</td>
<td>14.0-18.0</td>
<td>14.0-15.5</td>
<td>-0.36-0.3</td>
<td>1.86</td>
<td>7.78</td>
</tr>
<tr>
<td>Container ship C</td>
<td>15.5-19.5</td>
<td>13.0-14.0</td>
<td>0.19-0.3</td>
<td>1.00</td>
<td>5.72</td>
</tr>
<tr>
<td>Container ship D</td>
<td>16.0-19.0</td>
<td>12.0-13.2</td>
<td>0.90-1.6</td>
<td>1.15</td>
<td>6.71</td>
</tr>
<tr>
<td>Container ship E</td>
<td>14.0-17.0</td>
<td>13.3-14.3</td>
<td>0.01-0.19</td>
<td>0.27</td>
<td>2.29</td>
</tr>
</tbody>
</table>

Statistically, for container ships, the fuel consumption can save about 5.66% if the optimum trim is adequately used.

3.1.5 Conclusion of container ship

Based on the data collection and analysis from 5 container ships, the following conclusions can be drawn:

- At the constant draft, the least fuel consumption will reduce as the ship speed goes down;
- At the constant draft, the trim (the difference of draft aft minus draft fore) corresponding with the least fuel consumption will gradually decrease as the ship speed decreases, which indicates that less trim by stern less fuel consumption, i.e. the ship will save more energy as it is trimmed by bow;
Container ships can save about 5.66% of fuel consumption if the optimum trim is adequately used;

The method used by MTCC-Asia, i.e. collect data through flowmeters and draft measuring sensors and transmit data through BDS is a reliable method that can be used in collecting the data for determining the container ship optimum trim; and

The method by using the machine learning principle is a reliable method to determine the container ship optimum trim if the sufficient data is available.

3.2 Bulk carrier

3.2.1 Data pre-cleaning

The data collected from 5 bulk carriers are also pre-cleaned based on the similar reasons used in container ships. However, as the data collected from these bulk carriers is based on the manual input in a daily manner. Therefore, at current stages, total amount of data of each bulk carrier is insufficient for determining the ship optimum trim through the machine learning principle. As 5 bulk carriers are sister ships, i.e. they have similar ship characteristics, similar operating mode and sailing in the same sea area, the data collected from each bulk carrier can have the similar features. To handle the issue of insufficient data for each bulk carrier, all data collected from 5 bulk carriers is hence grouped into one training dataset for determining the optimum trim of bulk carrier through the machine learning principle.

3.2.2 Determination of primary speed and primary draft

The primary speed and primary draft for bulk carrier can be determined based on the histogram of the dataset, see in Figure 3.2.2-1 and Figure 3.2.2-2, respectively.

![Figure 3.2.2-1 Speed histogram of bulk carrier](image)
Therefore, the primary speed and primary draft for bulk carrier can be summarized in Table 3.2.2-1.

<table>
<thead>
<tr>
<th>Ship</th>
<th>Pri. speed (V1)</th>
<th>Pri. speed (V2)</th>
<th>Pri. speed (V3)</th>
<th>Pri. draft (d1)</th>
<th>Pri. draft (d2)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk carrier</td>
<td>10.5–11.5</td>
<td>11.5–12.5</td>
<td>12.5–13.5</td>
<td>13.5–14.5</td>
<td></td>
<td>All 3 primary speeds are corresponded with primary draft d1.</td>
</tr>
</tbody>
</table>

### 3.2.3 Determination of optimum trim for bulk carrier

Considering the range of primary speed and primary draft, the relationship between ship trim and fuel consumption for bulk carriers can be analyzed in Figure 3.2.3-1 (where horizontal axis and vertical axis represent trim and fuel consumption per hundred nautical mile).

The lowest points of red lines in Figure 3.2.3-1 signify the least fuel consumption corresponding with the ship optimum trim at the primary speed and draft. Even though due to the insufficient training data collected at present the fuel consumption does not have significant variation with the difference of ship draft, speed and trim, it can anticipate that
with the increase of training data, at the constant draft, the trim corresponding with the least fuel consumption will gradually move to the left side as the speed decreases, which indicates that less trim by stern less fuel consumption, i.e. the ship will save more energy as it is trimmed by bow.

### 3.2.4 Fuel-saving analysis for bulk carrier

Figure 3.2.4-1 shows the general relationship of ship primary speed, trim, draft and fuel consumption for bulk carrier, where primary speed (13.5-14.5kn) is used, horizontal axis and vertical axis represent trim and draft, respectively, and the blue points mean the real dataset collected.

![Figure 3.2.4-1 General relationship of ship primary speed, trim, draft and fuel consumption for bulk carrier](image)

Based on the real data collected, the real fuel consumption per hundred nautical mile for bulk carrier at the draft 10.5-11.5m and speed 13.5-14.5kn is about 14.58t. But using the machine learning method, when bulk carrier draft is under the same conditions of draft and speed, it anticipates the fuel consumption is about 14.03t, saving 0.55t, i.e. 3.77% if the optimum trim 0.00-0.01m is used.

### 3.2.5 Conclusion of bulk carrier

Based on the data collection and analysis from 5 bulk carriers, the following conclusions can be drawn:

- It can anticipate that with the increase of training data, at the constant draft, the trim corresponding with the least fuel consumption will gradually decrease as the speed decreases, which indicates that less trim by stern less fuel consumption, i.e. bulk carrier will save more energy as it is trimmed by bow.

- Bulk carriers can save about 3.77% of fuel consumption if the optimum trim is adequately used;
- The method used by MTCC-Asia, i.e. collect data through manual input and transmit data through BDS is a reliable method that can be used in collecting the data for determining the bulk carrier optimum trim; and

- The method by using the machine learning principle seems a reliable method to determine the bulk carrier optimum trim if the sufficient data is available.

3.3 Oil tanker

3.3.1 Data pre-cleaning

The data collected from 5 oil tankers are also pre-cleaned based on the similar reasons used in container ships. However, as the data collected from these oil tankers is based on the manual input in a daily manner the total amount of data of each oil tanker is insufficient for determining the ship optimum trim through the machine learning principle. As 5 oil tankers are sister ships, i.e. they have similar ship characteristics, similar operating mode and sailing in the same sea area, the data collected from each oil tanker can have the similar features. To handle the issue of insufficient data for each oil tanker, all data collected from 5 oil tankers is hence grouped into one training dataset for determining the optimum trim of oil tanker through the machine learning principle at present.

3.3.2 Determination of primary speed and primary draft

The primary speed and primary draft for oil tanker can be determined based on the histogram of the dataset, see in Figure 3.3.2-1 and Figure 3.3.2-2, respectively.
Therefore, the primary speed and primary draft for bulk carrier can be summarized in Table 3.3.2-1.

**Table 3.3.2-1 Primary speed and primary draft for bulk carrier**

<table>
<thead>
<tr>
<th>Ship</th>
<th>Pri. speed (V1)</th>
<th>Pri. speed (V2)</th>
<th>Pri. speed (V3)</th>
<th>Pri. draft (d1)</th>
<th>Pri. draft (d2)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil tanker</td>
<td>10.5-11.5</td>
<td>11.5-12.5</td>
<td>12.5-13.5</td>
<td>12.0-13.0</td>
<td>/</td>
<td>All 3 primary speeds are corresponded with primary draft d1.</td>
</tr>
</tbody>
</table>

### 3.3.3 Determination of optimum trim for oil tanker

Considering the range of primary speed and primary draft, the relationship between ship trim and fuel consumption for oil tankers can be analyzed in Figure 3.3.3-1 (where horizontal axis and vertical axis represent trim and fuel consumption per hundred nautical mile).

The lowest points of red lines in Figure 3.3.3-1 signify the least fuel consumption corresponding with the ship optimum trim at the primary speed and draft. Even though due to the insufficient training data collected at present the fuel consumption does not have
significant variation with the difference of ship draft, speed and trim, it can anticipate that with the increase of training data, at the constant draft, the trim corresponding with the least fuel consumption will gradually move to the left side as the speed decreases, which indicates that less trim by stern less fuel consumption, i.e. the ship will save more energy as it is trimmed by stem.

3.3.4 Fuel-saving analysis for oil tanker

Figure 3.3.4-1 shows the general relationship of ship primary speed, trim, draft and fuel consumption for oil tanker, where primary speed (11.5-12.5kn) is used, horizontal axis and vertical axis represent trim and draft, respectively, and the blue points mean the real dataset collected.

![Figure 3.3.4-1 General relationship of ship primary speed, trim, draft and fuel consumption for oil tanker](image)

Based on the real data collected, the real fuel consumption per hundred nautical mile for oil tanker at the draft 12.0-13.0m and speed 11.5-12.5kn is about 8.90t. But using the machine learning method, when oil tanker draft is under the same conditions of draft and speed, it anticipates the fuel consumption is about 8.39t, saving 0.51t, i.e. 5.73% if the optimum trim 0.00-1.13m is used.

3.3.3 Conclusion of oil tanker

Based on the data collection and analysis from 5 oil tankers, the following conclusions can be drawn:

- It can be anticipated that with the increase of training data, at the constant draft, the trim corresponding with the least fuel consumption will gradually decrease as the speed decreases, which indicates that less trim by stern less fuel consumption, i.e. oil tanker will save more energy as it is trimmed by bow.

- Oil tankers can save about 5.73% of fuel consumption if the optimum trim is adequately used;
The method used by MTCC-Asia, i.e. collect data through manual input and transmit data through BDS is a reliable method that can be used in collecting the data for determining the oil tanker optimum trim; and

The method by using the machine learning principle seems a reliable method to determine the oil tanker optimum trim if the sufficient data is available.

3.4 Conclusion of all types of ship

Based on the above data analysis from container ships, bulk carriers and oil tankers, the following conclusions can be drawn:

- The data collection method used by MTCC-Asia, i.e. collect data through manual input or electronic means and transmit data through BDS is a reliable method that can be used in collecting the data for determining the ship optimum trim;

- The method by using the machine learning principle is a reliable method to determine the ship optimum trim if the sufficient data is available.

- Statistics indicates that less trim by stern the ship has less fuel the ship consumes, i.e. the ship will save more energy as it is trimmed by bow; and

- If the optimum trim operation is adequately used on board, container ship and oil tanker can own nearly same fuel savings (5.66% and 5.73%, respectively), but both earn more fuel savings compared to bulk carrier (3.73%).

4. Guideline and video development

4.1 Purpose of developing guideline

The contributions made towards the mission of reducing GHG emissions from ships rely not only on the marine regulators, maritime administrators and ship managers, but also on seafarers. As the front-line operator of a ship, MTCC-Asia is fully aware that each seafarer can play a direct and significant role in promoting the ship energy efficiency and limiting or reducing GHG emissions from ships. Therefore, to facilitate readers, in particular seafarers, this guidelines publication is written in a user-friendly language through the avoidance of complex terminology and formula as far as possible and is widely disseminated to ships through visiting ships by MTCC-Asia, its branch office, pilot and shipping company when ships call at ports.

The output of this step is actually final goal of this project. All outputs are formulated based on the data collection and analysis and also results from the two steps of the track and feedback and the database of demonstration ships.
4.2 Contents of guideline

The guideline is finalized based on the observations obtained during the implementation of this pilot projects, comments of questionnaires from 15 demonstration ships and advices from IMO PCU experts. The contents of guideline are organized in five parts as follows:

- Chapter I presents the overall regulations developed and various actions conducted by IMO to enable the international shipping sector to meet the goal set in the United Nations Framework Convention on Climate Change (UNFCCC) for fighting the global climate change.

- Chapter II provides the basic theoretical knowledge regarding the ship trim optimization and machine learning method.

- Chapter III introduces in detail the operations of ship trim optimization based on the machine learning method, including the data preparation, system development and practical cases.

- Conclusions and precautions in operating ship trim optimization based on the machine learning method are summarized in Chapter IV.

- An operational guidance for users’ reference on simplified software of ship trim optimization based on the machine learning method is demonstrated in Chapter V.

The guideline together with the corresponding quick guidance and video after approved by IMO PCU are disseminated to ships. Figure 4.2-1 and Figure 4.2-2 show the cover pages of guideline, quick guidance and video, respectively.
5. Track and feedback

After the data collection and analysis, the draft version of guideline was developed and distributed to the demonstration ship, experts, participants of workshops and international meeting to seek the observations and comments for updating the contents of guideline. The main observations and comments obtained are as follows and were incorporated in the final version of guideline:

- Advantages of ship trim optimization by using machine learning method should be included;
- Ship short sea trial to obtain the basic ship data if the data from daily report is not sufficient should be mentioned;

- That the ship safety should not be influenced when using the ship trim optimization should be reminded;

- It is preferred to include the IMO documents related to the ship energy efficient operations and technologies in the guideline;

- The theory of ship trim optimization should be simplified;

- Precaution varied from the ship types when using the ship trim optimization based on the machine learning method should be identified.

In order to share the guidelines and other outputs of this project with the shipping industry as much as possible, MTCC-Asia assembles the guideline (printed and electronic versions), quick guidance (printed and electronic versions), video, Ship Trim Optimization Management System and a USB stick which stores all of these outputs as a package and delivered to seafarers on board through ship visiting, Shanghai Pilot Station, Ningbo Pilot Station and shipping companies. Figure 5-1 shows the package of the project output is delivered to seafarers on board through visiting the ships by MTCC-Asia officials. Figure 5-2 shows the package of the project output is delivered to seafarers on board by pilots.

![Figure 5-1 Package of project output delivered to seafarers on ship by MTCC-Asia](image)
As of the date submitting this report, the package of the project output was circulated to 2,329 vessels in total.

Some feedback messages from ships that received the package of the project output have been collected and summarized. From these feedbacks, it well demonstrates that the publications are very welcome and easily read by seafarers. Most comments provide the positive information that by reading the guidelines it has a general and good understanding of IMO regulations related to the reduction of GHG emissions from ships as well as how the trim optimization can contribute the ship energy efficiency promotion.

6. Database of ships using trim optimization

To date, 57 vessels has used the demo software of ship trim optimization based on machine learning method and considered this operation as one of supplement methods to improve their energy efficiency.

7. Examples of visibility activities

As per the Communication and visibility plan approved by the IMO PCU, MTCC-Asia has through social media, website, seminar, workshop, international meeting, equipment installed on board, onshore application system, ship visiting, E-learning course etc. disseminated the activities of the pilot project. The following figures show some examples of visibility activities
of the pilot project.

Figure 7-1 Ship visit and seminar dissemination through Social media

Figure 7-2 Onboard installation dissemination on website
Figure 7-3 Pilot project dissemination on seminar

Figure 7-4 Pilot project dissemination on workshop
Figure 7-5 Pilot project dissemination on international meeting

Figure 7-6 Pilot project dissemination through equipment installed on board
Figure 7-7 Pilot project dissemination through onshore application system

Figure 7-8 Pilot project package dissemination on website

Figure 7-9 Pilot project dissemination through E-learning course