A comprehensive assessment system for the maritime traffic environment

Kiyoshi Hara\textsuperscript{a}, Shinya Nakamura\textsuperscript{b}

\textsuperscript{a}Kobe University of Mercantile Marine, 5-1-1 Fukae-Minami Higashinada-ku, Kobe, Japan
\textsuperscript{b}Yusen Marine Science Inc., 2-3-6 Minami-Shinagawa Shinagawa-ku, Tokyo, Japan

Abstract

It is desirable when drawing up a maritime traffic environmental project or a project for consolidating port and harbour facilities, that the safety of the maritime environment for shipping-traffic is assessed quantitatively, and that the rationale of a given project and the proposed safety measures are evaluated in an objective manner.

In this report, the system flow and procedures to integrally assess the safety of the maritime traffic environment by systematically combining various simulation techniques are discussed first.

Subsequently, the quantitative risk evaluation procedure for collisions of ships in waters with a high traffic density, among the assessment procedures above, and an outline of the shipping traffic flow simulation capable of reproducing ships' movements, are described. In evaluating the results of simulations, a method introducing Subjective Judgement values (SJ-values) as indexes manifesting the subjective degree of danger felt by shiphandlers, is shown. The SJ-values were experimentally determined from simulator experiments using parameters representing the relation ship with other ships proceeding in the vicinity.

Finally, some of the results of studies conducted for the recent construction of new LNG berths in Tokyo Bay are introduced as an example of practical safety assessment in this field.

1. Introduction

Memories are still fresh among shipping concerns of the running aground and massive oil spill of an oil tanker in Alaska, of the collision between an LPG tanker and a cargo freighter involving a fire in Tokyo Bay, and of the collision of a large ship with a trunk road bridge in Brunswick, Georgia. If multiple major marine casualties occur, the impacts on the natural environment and society are immeasurable. On the other hand, it is very important for a sound socioeconomic development to utilize the sea for marine airports, roads, bridges, pleasure bases, fish culture, etc.
To draw up plans for new maritime traffic systems, and port and harbour facilities, it is necessary to quantitatively grasp the safety of the shipping-traffic environment, and to evaluate the rationale of the plans and the proposed safety measures. Several simulation techniques have been developed and applied to help to quantitatively grasp the safety of the shipping-traffic environment. Demand for a sophisticated system combining these simulation techniques to ensure an integrated assessment of the safety of the shipping-traffic environment, is expected to increase in the future. This report discusses a procedure that assesses the safety of the shipping-traffic environment in an integrated manner.

2. Flow of a safety assessment system for the shipping-traffic environment

Fig. 1 is a schematic of a general system that assesses the safety of the shipping-traffic environment in relation to a marine transport project. This represents the flow of the safety assessment system using the simulation techniques proposed and developed by the authors of this report. The techniques have recently almost taken the form of the standard safety assessment system of the shipping-traffic environment, applicable to marine transport projects or consolidation plans for port and harbour facilities in Japan.

The flow of the safety assessment system can be broadly divided into the following three:
- Assessment of the rationales for a marine transport plan.
- Assessment of the degree of danger of collisions in a specific sea area, and assessment of the traffic volume on a traffic route.
- Assessment of the shiphandling environment and port and harbour facilities.

The contents of the assessments are outlined below.

2.1. Assessment of the rationale of the transport plan

In assessing a marine transport project, the volume of marine transport and means of transportation are assessed, and simulations are carried out on the operating rate of berths using the theory of queue management including the relationship between the marine

![Fig. 1. Schematic of the flow of the safety assessment system for shipping-traffic environment.](image-url)
transport potential and the capacity of the shore reception facilities. Through these assessments, the optimum balance between the transport plan and the capacity of reception facilities, without having a significant number of ships waiting outside a port, can be sought. Fig. 2 shows an example of the simulation output plan indicating the berth operating rate in a coal transport project.

2.2. Collision risk assessment of a sea area and traffic volume assessment in a traffic route

For a newly projected marine transport plan, if ships proceed through straits and waters close to large ports and bays with a high traffic density, it is necessary to carry out a collision risk assessment and a traffic volume assessment. Based on the results of these investigations, the significance of the effects of increased collision risk caused by the marine transport plan upon the sea area of high traffic-congestion is evaluated; whether or not is the capacity of the traffic route has any allowance evaluated, and the acceptability of the proposed marine transport plan, from the viewpoint of traffic congestion is judged. In collision risk assessments, passages which routes’ and time belts’ are most desirable from the viewpoint of the safety of shipping traffic are specifically studied.

In assessing the degree of traffic congestion, it is necessary to extract sea areas on the basis of the new marine transport plan for surveying actual traffic conditions. This survey is intended to grasp the number of ships involved, ships tracks, and speed, using radars.
Fig. 3. Results of shipping-traffic investigation.

Fig. 4. Photos showing shiphandling simulator experiments.
Based on the results of the survey, predictions are made about the impact of other projects upon marine traffic and probable shipping volume due to the trend of the economy, and simulations are carried out to assess the risk of collisions and to estimate shipping-traffic volume in the future. The simulations include a marine-traffic flow simulation to assess collision risk, the shipping-traffic volume simulation to estimate traffic volume, and a traffic control simulation to investigate the need for shipping-traffic control. The shipping-traffic flow simulation and its evaluation method are discussed in greater detail in Chapter 3.

Fig. 3 is a ship track chart drawn on the basis of the results of the shipping-traffic survey carried out off the Port of Yokohama, using radars. These results of experimental surveys serve as the basic data for preparing the shipping-traffic flow simulation model to be described later.

2.3. Assessments of shiphandling environment and port and harbour facilities

In assessing the shiphandling environment and the port and harbour facilities plan, systematic experiments are carried out using shiphandling simulators capable of generating realistic images of marine facilities, aids to navigation, and natural environment with moving objects in their relation with degrees of difficulty in shiphandling, giving a strong on-the-scene feeling in the wheel house. In evaluating degrees of shiphandling difficulties, the shiphandling process is divided into the course-keeping phase, course-changing phase, headway killing phase, turning phase and the phase of lateral ship motions, each of which serves as an element in evaluating shiphandling difficulties. For each such evaluation element, the principal evaluation elements and principal evaluating indexes are determined, with that an evaluation of shiphandling difficulties is carried out on the results of simulator experiments under various conditions. Fig. 4 shows photos covering simulator experiments. As example of the shiphandling difficulty evaluation index, the distribution of deviation from the point at which the shiphandling phase changes from one phase to another (tentative goal) is shown in Fig. 5. These are the deviation of ships at the tentative goals compared with the results of shiphandling involving external forces and errors with the standardized
shiphandling results (i.e., shiphandling without involving external forces and errors). The ellipsoid drawn in dotted lines in the Figure shows the allowable limit of deviation under the general interactive relationship between the shiphandler and marine facilities.

To assess the safety of a ship while laying alongside a berth and the limits for cargo operations, studies are conducted by the laid ship motion simulation. In this simulation, the motions of a ship in wind, waves, and swells are calculated with six degrees of freedom, whereby the safety of a ship laid in motions is assessed from the mooring rope tension and the movements of the ship due to motions.

3. Collision risk evaluation with a marine traffic flow simulation

In marine transportation, the collision risk evaluation is an important assessment item from the viewpoint of assessing safety, because shipping traffic is two-dimensional and speed regulation is difficult. From the evaluation systems stated in Chapter 2, degrees of collision risk and items for assessing the degree of traffic congestion are discussed in detail below.

3.1. Outline of marine traffic simulation

Setting the detailed explanations on simulation models aside, the marine traffic simulation introduced here grasps the traffic environment in a specific sea area quantitatively on the basis of the meeting situation of ships and giving-way manoeuvres, and has the following features:

- All ships navigating in the simulated sea area proceed with an algorithm that carries out collision averting manoeuvres close to real shiphandling for collision avoidance. It is, therefore, feasible to reproduce the shipping traffic very close to the real image on the simulator display.
- Not only the collision risk evaluation of the entire sea area under study, but also the judgement standard for collision risk computed on the basis of the results of the shiphandlers' consciousness survey (simulator experiment) are incorporated into the ship, for which the generation of collision risk is to be proved. Because the ship to be evaluated is selected according to such a standard, the results obtained are very close to the judgement made by an experienced shiphandler.

3.2. Simulation examples

A certain degree of dispersion is created for the encounter of ships in this simulation, because random numbers are used for simulating the ships involved. It is necessary to simulate as many meeting situations as possible to reduce the dispersion. It was, therefore, established that calculations were repeated for each simulation until a total of 2000 ships were generated. The time intervals for generating ships and collision judgements were five seconds. The ship track chart simulated is shown in Fig. 6.
3.3. Evaluation method for simulation results

As the index to evaluate the degree of difficulty of average shiphandling in an experimental sea area, the number of collision-averting manoeuvres carried out in the ship in a marine traffic flow simulation or the mean value of the number of collision-averting manoeuvres of the other ship can be mentioned. However, in assessing the safe navigation route for a ship or the safe time belts, an evaluation of collision risk from the viewpoint of the ship to be investigated is necessary. And, the evaluation must reflect the shiphandler’s consciousness. Factors indicating the degree of collision risk felt by the shiphandlers are determined experimentally, and the results of the simulation were evaluated by applying the equation of the evaluation comprising these factors. The contents are shown below.

3.3.1. Subjective collision risk felt by the shiphandler

As an index to express the degree of collision risk of a ship felt by the shiphandler, the concept of Subjective Judgement (hereafter called the ‘‘SJ-value’’) was introduced in this study. The SJ-value expresses quantitatively the degree of collision risk with another ship felt by the shiphandler. The parameters were assessed experimentally, and the following equation of evaluation (1) was introduced with variables: the relative distance between the ship and another ship, the rate of change of the relative position of another ship viewed from the ship, and the relative speed between the ship and another ship.

\[ SJ_i = a_i \Omega + b_i \mathbf{R}' + c_i \mathbf{R}' + d_i, \quad (1) \]

where
The SJ-values and the degree of collision risk felt by the shiphandler have the following relationship:

- Extremely dangerous: $SJ = -3$
- Dangerous: $SJ = -2$
- Slightly dangerous: $SJ = -1$
- Cannot say which: $SJ = 0$
- Slightly safe: $SJ = 1$
- Safe: $SJ = 2$
- Extremely safe: $SJ = 3$

3.3.2. Evaluation index

Examples of an evaluation index using the SJ-value are shown here. The concrete results of evaluation are stated in Chapter 4.

- Number of encounters per unit time with ships whose SJ-value is $-1$ or less.

This is the number of encounters with ships calling the attention of the ship understudy. The SJ-values of a ship for other ships are computed constantly during the simulation period, and the number of encounters with the ship (calling the attention) whose SJ-values (subjective degree of collision risk) become a threshold value ($SJ \leq 1$) is integrated, and by dividing this by the integrated value of hours run, whereby the number of encounters per unit time (e.g. 10 minutes) is obtained. By this procedure, a quantitative evaluation comparable to the real feeling of the shiphandler becomes possible.
The sea area under study is divided into meshes. The SJ-value making the degree of collision risk to be \(-1\) (slightly dangerous) or less is integrated for each mesh according to Eq. (2). The result thus obtained is divided by the simulation time and expressed by a shaded graduation on the SJ-value distribution chart.

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**Fig. 7.** SJ-value distribution of LNG carriers on the Northern route.

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**Fig. 8.** SJ-value distribution of LNG carriers on the Southern route.
Table 1
Number of encounters with ships calling attention (SJ-value: −1 or less) as viewed from the ship under study

<table>
<thead>
<tr>
<th>Time belt</th>
<th>Mean No. of ships encountered in 10 min (SJ = &lt; −1)</th>
<th>Standard deviation</th>
<th>Ship under study No. of ships generated</th>
<th>Ship under study Mean time of passage (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ship under study on the Northern route</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07 ~ 08</td>
<td>1.9</td>
<td>0.77</td>
<td>35</td>
<td>68.9</td>
</tr>
<tr>
<td>08 ~ 09</td>
<td>1.0</td>
<td>0.43</td>
<td>55</td>
<td>69.8</td>
</tr>
<tr>
<td>09 ~ 10</td>
<td>1.8</td>
<td>0.82</td>
<td>52</td>
<td>71.5</td>
</tr>
<tr>
<td>10 ~ 11</td>
<td>2.4</td>
<td>1.19</td>
<td>33</td>
<td>69.5</td>
</tr>
<tr>
<td>11 ~ 12</td>
<td>2.3</td>
<td>1.05</td>
<td>36</td>
<td>69.1</td>
</tr>
<tr>
<td>12 ~ 13</td>
<td>1.8</td>
<td>0.94</td>
<td>49</td>
<td>70.6</td>
</tr>
<tr>
<td>13 ~ 14</td>
<td>3.2</td>
<td>3.67</td>
<td>48</td>
<td>70.5</td>
</tr>
<tr>
<td>14 ~ 15</td>
<td>2.7</td>
<td>1.70</td>
<td>40</td>
<td>68.9</td>
</tr>
<tr>
<td>15 ~ 16</td>
<td>2.2</td>
<td>1.01</td>
<td>38</td>
<td>69.1</td>
</tr>
<tr>
<td><strong>Ship under study on the Southern route</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07 ~ 08</td>
<td>3.5</td>
<td>1.28</td>
<td>36</td>
<td>57.5</td>
</tr>
<tr>
<td>08 ~ 09</td>
<td>1.7</td>
<td>0.60</td>
<td>53</td>
<td>60.7</td>
</tr>
<tr>
<td>09 ~ 10</td>
<td>2.9</td>
<td>0.92</td>
<td>51</td>
<td>60.1</td>
</tr>
<tr>
<td>10 ~ 11</td>
<td>4.0</td>
<td>1.23</td>
<td>33</td>
<td>59.0</td>
</tr>
<tr>
<td>11 ~ 12</td>
<td>4.0</td>
<td>1.21</td>
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<td>58.6</td>
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<tr>
<td>12 ~ 13</td>
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<td>59.0</td>
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<td>13 ~ 14</td>
<td>4.2</td>
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<td>15 ~ 16</td>
<td>3.5</td>
<td>1.54</td>
<td>38</td>
<td>58.1</td>
</tr>
</tbody>
</table>

The SJ-value distribution is expressed by Eq. (2). By looking at the shaded graduation of meshes on this distribution chart, where in the sea area under study is the number of encounters with ships calling for the highest attention can be identified.

\[
SJ-value\ distribution = \frac{\sum_{k=1}^{n} \sum_{l=1}^{m} |SJ_{kl}| \cdot t}{60 \cdot T}, \tag{2}
\]

where

- \( SJ' = \) SJ value under a threshold value (SJ value = \( \leq -1 \)),
- \( n = \) number of ships navigated during the simulation,
- \( m = \) number of calculating SJ values during the simulation,
- \( t = \) calculation step time intervals for SJ values (s),
- \( T = \) simulation time (min).

4. Examples of safety evaluation examples for the shipping traffic environment

Examples of the safety evaluation implemented by using the evaluation systems described above are introduced here, taking up some recent assessments in Japan.
The object studied is a project to construct a new LNG berth in the vicinity of the Port of Yokohama within Tokyo Bay for large LNG carriers.

Firstly, the scale of the projected berth and the planned volume of LNG carried were assessed and concluded to be trouble-free. In assessing the degree of traffic congestion, the capacity of traffic volume in the URAGA SUIDO Traffic Route located near the mouth of Tokyo Bay was investigated. The results of the investigation showed that the estimated traffic volume would reach a critical point depending on time belts, and concluded that the passage of large LNG carriers through the Traffic Route should be scheduled to avoid the time belts when the shipping traffic is particularly heavy.

In assessing the degree of collision risk after passing URAGA SUIDO Traffic Route, investigations of safe routes for entering port manoeuvres up to the planned berth and time belts of passage were carried out using the SJ-values stated in Chapter 3. Fig. 7 shows the distribution chart of SJ-values viewed from the ship under study (incoming LNG carrier) when she proceeds along the northern route for entering port manoeuvres in the time belt with the highest traffic density. Fig. 8 shows the distribution chart of SJ-values when the ship proceeds along the southern route in the same time belt. Table 1 is a list of the number of encounters making the SJ-values in 10 minutes to -1 or less. These results show that the northern route for entering port manoeuvres is safer. The highest value of the mean number of encounters in 10 minutes (SJ values less than -1) was 5.2 for the southern route for entering port manoeuvres from 1400 to 1500 hours. Recognizing the general principle introduced from the simulator experiments that if the number of encounters with ships calling for attention in 10 minutes exceeds 5, ship handling becomes difficult, the time belt for entering port manoeuvres through the southern route was established to be before
1000 hours, and that the passage through the northern route for entering port manoeuvres would be desirable for safety reasons.

For assessing the shiphandling environment and the port and harbour facilities, the geometric configurations and the orientation of the planned berth were fully investigated by shiphandling simulators and mooring simulations. As a result the preferred geometric configuration of the berth, critical sea and weather conditions, required power capacity of tugs and number of tugs were recommended. Examples of ship track charts chosen from the results of the shiphandling simulator experiments are shown in Fig. 9.

5. Concluding remarks

To quantitatively grasp the safety features of the maritime traffic environment involved in a marine transport project or a consolidation project of port and harbour facilities for assessing the rationale of the projects and the proposed safety measures in an objective way, a variety of simulation techniques have been systematically combined and overall safety was investigated through the flow of assessing systems shown.

As an integral part of the assessing system, the marine traffic flow simulation was outlined, and the collision risk evaluation method was described. A technique to express the subjective degree of danger (SJ-value) felt by the shiphandler using parameters such as the relative distance to another ship and the rate of change in the direction was shown, whereby the results of the assessment of the sailing route of a ship and passing time belt using SJ-values were exemplified. Not only the collision risk assessment as a mean value of the entire sea area under study, but also the subjective degree of collision risk as viewed from the ship under study could be expressed in a form close to the real feeling and consciousness of the shiphandler. As a result, the effectiveness of the assessing system could be demonstrated.

As an example of an assessment of the safety of the shipping traffic environment, part of the results of the safety assessment for the plan to construct a new LNG berth in Tokyo Bay, Japan was shown.

The authors of this report wish to mention before concluding that they have advocated an idea that if SJ-values for assessments introduced at this time could readily be understood by the shiphandlers of each ship and VTS operators, it suggests the possibility that shiphandlers of many ships can manoeuvre their ships with the same feeling for degree of collision risk, which is extremely effective for enhancing overall safety.

References
