A Study on a Dynamic Traffic Management System based on Virtual and Synthetic AtoN AIS System

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Abstract
The rapid pace of technological development, the growing maritime traffic, the growing fishing industry, and the limitations and constraints imposed by nature make the imperative to develop a radical new approach to the traditional maritime traffic and aids to navigation management systems in order not to be superseded. This paper investigates the feasibility of a Space-Time based Dynamic Traffic Management System that can evolve within itself to manage the growing traffic and aids to navigation, using Virtual and Synthetic AtoN AIS system technology.

The authors build an AIS Marine Traffic Database for Tokyo Bay (May 16th – October 7th 2007), using actual dynamic data provided by ships, and static data provided by a commercially built database. After simulating part of the data (16-31 May 2007) in Uraga Suido Traffic Route, two Time Gates (04h00-08h00, 17h00-24h00) and a Dynamic Zone (width=250m) are determined. The proposed Dynamic Traffic Management System reduced the marine traffic density (Mean and Maximum values) by around 21% for both north and south bound lanes. As for the future research the study will be expanded to cover all available data, and include other parameters in assessing the Time Gates and the width of the Dynamic Zone.

Keywords: Marine traffic, AIS, Marine traffic database, Virtual AtoN, Synthetic AtoN

1. Introduction
The traditional hardware designed to aid navigational safety- lights, buoys, channel markers and the like, in association with the corresponding shipborne navigational equipment was being supplemented and gradually superseded, by a new generation of information and communication-based tools, such as Vessel Traffic Service (VTS), the Automatic Identification System (AIS), the Global Positioning System (GPS), Electronic Navigation Charts (ENC) and others. This state of rapid technological development and change is occurring not just in the arena of electronics, but also, and perhaps even more crucially, in the design and operation of the ships themselves. Ships are getting larger; ships are getting faster; and ships’ crews are getting smaller – all of which make the need to support safe voyages and the task of providing appropriate and effective Aid to Navigation (AtoN) more challenging than ever before.

Furthermore, because of the growing maritime traffic, and the limitations and constraints imposed by nature, such as depth contours and natural obstacles without forgetting the growing fishing industry all of which make the traffic routes almost impossible to expand, we are fast approaching a watershed in matters of navigable waters.

Regarding Tokyo Bay, besides the maritime traffic management challenges and issues stated before, all ships (inbound and outbound) are processed through the bottle neck of Uraga Suido Traffic Route with its width of 1760m, and an area that represents only 2% of Tokyo Bay area.

The imperative to develop a radical new approach to

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the traditional VTS systems, management of AtoN and traffic is growing. Most of the fundamental elements for such a change exist, so far the AIS technology (Virtual and Synthetic AtoN AIS System)\(^5\), ENC, and the coming Global Navigation Satellite System (GNSS). The challenge now is how to combine and integrate them into a system that will have a significant beneficial effect far in the future, while simultaneously reduce the burden on ships and shore.

In this paper the feasibility of a Space-Time based Dynamic Traffic Management System for a prefixed navigation space (DTMS), using Virtual and Synthetic AtoN AIS system technologies\(^5\) is investigated. The system as currently envisaged would incorporate the aforementioned new technology in a structured way providing an accurate, secure and cost effective traffic management system that can evolve within itself in order not to be superseded by the growing traffic volume.

2. DTMS Overview

2.1 Components

The DTMS components would be as follows:
- Accurate, Comprehensive and up-to-date ENC, covering the entire designated geographical area.
- Accurate and reliable electronic positioning system with a fail; safe performance, as theoretically provided by the GNSS.
- Ship related data are provided in electronic format.
- Accurate, clear, fully integrated, user friendly display of the above information onboard ship and ashore (VTS and AtoN Providers).
- Information prioritization and alert capability in risk situations both onboard and ashore.
- Reliable transmission of distress alerts and other related safety information.
- Reliable transmission protocols without jeopardizing the security of the above information.

2.2 Architecture

The DTMS architecture would be as shown in Fig.1. The core elements of the system are the Dynamic Zone (Space) and Time Gate (Time) as highlighted in Fig.1.

2.3 Concept

The DTMS concept contains two phases:

Phase 1: Within the Time Gate

The Dynamic Zone (DZ) (called a reversible lane in Land Transportation Engineering nomenclature) is a lane in which traffic may travel in either direction, depending on the traffic condition through a fixed time interval called Time Gate. The DZ is made by shifting the separation line to one side or another to add a prefixed area to the lane where the traffic is congested. Typically, it is meant to improve the traffic flow during congested hours.

Phase 2: Outside the Time Gate

The DTMS is similar to any traffic route with two lanes or to any traffic separation scheme with no separation zone.

2.4 AtoN AIS System Advantages

The implementation of Virtual and Synthetic AtoN AIS Systems have many advantages, which includes but not limited to:
- Reduce Cost
  - Reduction of the number of conventional AtoN required
  - Fewer man-hours to update and maintain
  - Reduce energy requirement
- Greater range than conventional AtoN
- Timeliness/immediacy
- More efficient and flexible shipping operations.
- Remove the need to deploy more constellations.

* Useful Definitions \(^5\)

1- AIS: Universal Shipborne Automatic Identification System

2- AtoN (Aid to Navigation): A device or system external to vessels that is designed and operated to enhance the safe and efficient navigation of vessels and/or vessel traffic. (IALA Navguide)

3- Virtual AtoN: Digital symbol represented on vector-based charts indicating navigational hazards and AIS-equipped vessel movement.

4- Synthetic AtoN AIS System: It is not absolutely necessary for an AIS unit to be fitted to an AtoN such as a buoy for AIS technology to be used. Where a buoy is monitored by some other means an AIS message can be transmitted from an adjacent shore station so that to the mariner the message appears to come from the buoy itself. This facility is termed Synthetic AtoN AIS System.

5- Virtual AtoN AIS System: There is no need to deploy an AtoN to make it appear on the screen of a Radar/ENC. An AIS message can be sent from an adjacent shore station so that to the mariner the message appears to come from a buoy that doesn’t exist in fact. Such aids would of course only be visible to AIS equipped ships. This facility is termed Virtual AtoN AIS System.

The use of AIS to mark new dangers and established new routes or exclusive zones, offers the potential for a significant improvement in matters of traffic management and first response time to wrecks and other new dangers.
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3. AIS Marine Traffic Database

To carry out our DTMS feasibility study we needed a real marine traffic data for simulation. Contrary to the marine traffic databases based on AIS data (3), the previously built marine traffic databases (mainly indexed by time) are based on direct observation, Radar/ARPA images, and/or automatic wake extraction form radar signals. Those databases give real image of the traffic, but present many limitations related to the ship's static data and to the connectivity and adaptability with the other commercially built databases (mainly indexed by ship's MMSI/IMO numbers).

The built AIS Marine Traffic Database (hereafter called AIS Database) includes ships' actual dynamic data provided by ships, and ships' static data provided by a commercially built database for more reliability.

3.1 AIS Data Acquisition

To build the AIS Database we collected Raw AIS data from the Remote Radar/AIS Network System for observing Vessel Traffic in Tokyo Bay (2). The acquisition process is shown in Fig.2.

Fig.1 DTMS Architecture and Components

- Ability to provide unique information for a particular vessel or class of vessel.

Fig.2 AIS Data Acquisition Process

MMSI, AIS class, Navsat, ROT , SOG, COG, Acceleration, Longitude, Latitude, Heading, Time Stamp, Version, IMO Nbr, AIS code, Antenna position1, Antenna position2, Antenna position3, Antenna position4, Deviation, ETA, Draft, Destination, DTE.

Fig. 3 Data Format of AIS Received Data
Table 1 Storage Size of AIS Data Warehouse

<table>
<thead>
<tr>
<th>Total Size</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB</td>
<td>22</td>
<td>3.2</td>
<td>5</td>
<td>3.4</td>
<td>4</td>
<td>4.9</td>
</tr>
</tbody>
</table>

The data stored in the AIS Data Warehouse presents many issues that can be summarized in the following:
- Discontinuity and interval of plotting is not stable.
- Sometimes data is corrupted.
- Most of the time ship's static data contain errors.

3.3 Static AIS Database

Since the Static Data provided by ships contain errors, we used the static data provided by the World Shipping Encyclopaedia (Lloyd's Register Fairplay .Ltd) with its 114466 ships and 335 data fields of Ship's static data.

However, for our research we used only 11 fields that represent a vital importance to assess the maritime traffic in Tokyo Bay. The Static AIS Database data format is shown in Fig 4.

Fig.4 Data Format of Static AIS Database

IMO Nbr, LOA, Draft, Beam, Gross Tonnage, Flag, Vessel Type, Propulsion Type, Thruster Type, Hull Type, Classification Society.

Table 2 Storage Size of AIS Database

<table>
<thead>
<tr>
<th>Total Size</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB</td>
<td>8</td>
<td>953</td>
<td>1.8</td>
<td>1.37</td>
<td>1.54</td>
<td>2.1</td>
</tr>
</tbody>
</table>

3.4 AIS Database

To build the AIS Database we proceeded as follows:
1. Process the data provided by the AIS Data Warehouse through a user program in an offline data processing that contains but not limited to: Data Filtering, Data Interpolation, and Data Recompilation.
2. Joined together, the data provided by the Static Database and the processed data through a user program to build the AIS Database as shown in Fig.5

The AIS Database provides accurate ships' static and actual dynamic data including 19 fields of data, with a plotting frequency of 30 seconds, from May 16th to October 31st, 2007.

The AIS Database data can be exported by a conditional query as a Text file, Spread sheet, XML, CSV file, and Database format. The storage size of the AIS Database data is shown in Table 2 and the AIS Database data format is shown in Fig 6.

3.5 AIS Database GUI

We provided the AIS Database with a GUI (Graphical User Interface) to carry out simulations and assessment of the maritime traffic management as shown in Fig.7.

4. DTMS Feasibility Study

To carry out our feasibility study we did some simulation for the data provided by the built AIS Database.

4.1 Simulation Components

The simulation components are as follows:
- Area: Uraga Suido Traffic Route (USTR)
- Data: AIS Database
- Duration: from May 16th to May 31st, 2007
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- Frequency of Plots: 30 seconds
- Total Size: 953 Mb
- Number of Ships Plotted: 1657 ships

Fig. 7 AIS Database GUI

4.2 Time Gate
To determine the Time Gates we processed the data, Mean Value (MV) and Ships Density, through the period of time to detect any tendency related to the ships navigating in USTR (North and South Bound Lane).

Through the results shown in Fig.8 and Fig.9, it is clear that there are two phases:
1. Morning Phase: Where the North Bound Lane is congested.
2. Evening Phase: Where the South Bound Lane is congested

After assessing the ships navigation tendencies we decided to establish two Time Gates, where
1. Morning Time Gate: 04h00 – 08h00
2. Evening Time Gate: 17h00 – 24h00

Fig. 8 Ships’ Mean Value in USTR (16-31 May 2007)

4.3 Dynamic Zone (DZ)
To determine the DZ width we proceeded as follows:

Step1: Determined the Ship/Ship Clearance, while navigating in USTR, between the North Bound Lane and the South Bound Lane.

After observing the traffic we found that the Ship/Ship Clearance is around 150 m per lane.

Step2: Determine the Average size of ships sailing in USTR, and classify the ships size-wise.

The LOA has been chosen as the main dimension to the GT classification to determine the size and the dimension of the ships calling USTR.

From Table 3 it can be noted that the Mean LOA and the Mean GT are 158.7 m and 24061.5 t respectively. However, less than 25% of the ships calling USTR have a LOA>200m and more than 50% have a GT less than 10000 t as show in Table 4 and Table 5.

Table 3 USTR Ship Mean Size and Dimension

<table>
<thead>
<tr>
<th>LOA (m)</th>
<th>Nbr Ships</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>964</td>
<td>35</td>
<td>352.6</td>
<td>158.7</td>
<td>73.5</td>
<td></td>
</tr>
<tr>
<td>964</td>
<td>199</td>
<td>160889</td>
<td>24061.5</td>
<td>29345.4</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 USTR Ship Size Relative Ratio based on LOA

<table>
<thead>
<tr>
<th>Ships’ Size</th>
<th>Relative Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOA&lt;= 200m</td>
<td>77.7 %</td>
</tr>
<tr>
<td>LOA&gt; 200m</td>
<td>22.3 %</td>
</tr>
</tbody>
</table>
Table 5 USTR Ship Size Relative Ratio based on GT^{(4)}

<table>
<thead>
<tr>
<th>Ships’ Size</th>
<th>Relative Ratio</th>
<th>Cum. Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Ships</td>
<td>GT&lt;1000t</td>
<td>5.70%</td>
</tr>
<tr>
<td>Midsize Ships</td>
<td>GT&gt; 1000t</td>
<td>45.00%</td>
</tr>
<tr>
<td>Large Ships</td>
<td>GT&gt; 10000t</td>
<td>49.30%</td>
</tr>
</tbody>
</table>

Ships of the same category are generally analogous regardless their size, so their main dimensions are approximately proportional to 1/3 power of the ship size. To confirm this analogy and obtain the main dimensions according to the ship size, we applied the Logarithmic Regression Analysis method \(^{(6)}\) represented by the following equation. \(Y = a X^6\)

Where:
- \(Y\) : LOA
- \(X\) : GT
- \(a, b\) : Coefficients

The results of the analysis of the ships calling USTR are shown in Fig.10. The actual analysis confirms high correlation where \(Y = 7.1319 * X^{0.3222}\), the Coefficient of determination \(R^2 = 0.9478\), and \(b\) is confirmed to be near 1/3.

![Fig.10 Distribution Diagram of LOA and GT](image)

Furthermore, through observation we concluded that ships with a \(\text{LOA}>200\text{m}\) navigate in one line through the USTR, in the middle of the lane, however the other ships could navigate in two lines.

Step3: Assess the Navigation space allocated to each ship by implementing the bumper model applied in Tokyo bay.

Assuming that all the ships navigating in USTR are VLCC (\(\text{LOA}=333\text{m}, \ B=63\text{m}\)), and applying the bumper model used in Tokyo bay (\(\text{LOA}>300\text{m} \Rightarrow 2L \times 2L \times 0.8L (\text{Front} \times \text{Stern} \times \text{Beam})\)) \(^{(1)}\).

From the results of Step1 and Step2, and knowing that the minimum width of USTR is 852 m per lane, we decided to design the DZ in such a way to meet the following conditions:

\[
\begin{align*}
\text{(a)} & \quad \text{Lane width} + \text{DZ} = 1066\text{m} \\
\text{(b)} & \quad \text{Lane width} - \text{DZ} = 533\text{m}
\end{align*}
\]

Where:
- (a): Two VLCCs navigating parallel to each other with no bumper intersection
- (b): One VLCC navigating in the Middle of the traffic route, with no bumper intersection with the ships navigating in the other lane.

By solving the equations (a) and (b) we found that the allowed DZ width should range between 214 m and 319 m.

However, by implementing the DZ, the USTR should support three flow lanes for VLCC. From this assumption the passing distance will be represented by the difference between the minimum and maximum allowed DZ width (105m -1.6B).

Assuming that passing occurs only due to two-way traffic, resulting in head-on-passing, and because overtaking is carried out at a low relative speed \(^{(6)}\), the passing distance is divided equally by three (35m) where one segment is added to DZ width and the two other segments are added to the lane without the DZ.

So the equations (a) and (b) are changed to:

\[
\begin{align*}
\text{(c)} & \quad \text{Lane width} + \text{DZ} = 1101\text{m} \\
\text{(d)} & \quad \text{Lane width} - \text{DZ} = 603\text{m}
\end{align*}
\]

By solving the equations (c) and (d) the DZ width is found to be 249m. To satisfy the above conditions and to ease computations, we designed the DZ = 250m

4.4 Simulation Results

Through Fig.11 and Fig.12 we can see that by implementing the DTMS:

1. **Morning Time Gate** (04h00-08h00):

The traffic density in the North Bound Lane is reduced by 22.4% with a maximum of 0.831 Ships/km2. However an increase followed in the South Bound Lane to reach a maximum of 0.927 Ships/km2.
2. *Evening Time Gate (17h00-24h00):*

The traffic density in the South Bound Lane is reduced by 21.6% with a maximum of 0.819 Ships/km². However an increase followed in the North Bound Lane to reach a maximum of 0.933 Ships/km².

The summary of the simulation results are shown in Table 6 where only maximum traffic density peaks are displayed:

<table>
<thead>
<tr>
<th></th>
<th>NB Lane (Max Density)</th>
<th>SB Lane (Max Density)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning Time Gate</td>
<td>0.831 (-22.4 %)</td>
<td>0.927</td>
</tr>
<tr>
<td>Evening Time Gate</td>
<td>0.933</td>
<td>0.819 (-21.6 %)</td>
</tr>
</tbody>
</table>

Furthermore, a comparison of the maximum traffic capacity of one lane of the USTR to the ships’ LOA shows and increases in the traffic capacity where the DZ is added to the lane and vice versa a decrease where it is subtracted as shown in Fig. 14.

The ratio of the multiple encounters to the total encounters is proportional to the traffic density, whereas the number of simple encounters is proportional to the second power of traffic density, and the number of multiple encounters is proportional to the third power of traffic density(6).

Therefore, a decrease of 20% in the traffic density will lead to an expected decrease of around 36% in the number of simple encounters, and to an expected decrease of around 49% in the number of multiple encounters.

### 5. Conclusions

In this paper, the feasibility of a Space-Time Dynamic Traffic Management System based on Virtual and Synthetic AtoN AIS System is discussed. The concept of the Dynamic Zone, which is a lane in
which vessels may navigate in either direction depending on the traffic condition through a fixed time interval called Time Gate, is introduced aiming to reduce the traffic congestion in a fixed marine traffic route space.

Building an AIS Marine Traffic Database, based on actual dynamic data provided by ships and static data provided by the World Shipping Encyclopaedia, has permitted to us to assess the traffic effectively inside Uraga Suido Traffic Route, and also to have a global view about the traffic inside Tokyo Bay. A part of the data provided by the database (16-31 May 2007) was used to carry out simulations.

The proposed Dynamic Traffic Management System reduced the marine traffic density (Mean and Maximum values) by around 21% for both lanes. Although an increase of density followed in the opposite lane to the Dynamic Zone, but the system managed to keep it under 1 ship/km2. Furthermore, a consequent decrease in the estimated encounter number can be achieved, even though more research is need for this matter.

With analogy to the Reversible Lanes (9) implemented in land transportation, many issues will be faced while implementing the DTMS such as the confusion and/or misunderstanding that can follow the transition period when the DZ is put into service, and also the length of the transition periods itself, which is the time required for the last ship entering the lane to exit. To solve these issues the role of VTS and law enforcement are highlighted as the main key components of the DTMS. However, by using the Virtual and Synthetic AtoN AIS System technology, a virtual moving barrier could be implemented behind the last ship until clearance, or until a designated point where the ship is instructed another course to clear the space allocated to the DZ.

As for the future research, the authors will extend this study to cover all available data, and include other parameters in the risk assessment such as risk of collision, risk of grounding, seasonal effect and also the recommendations provided by PIANC(5). The results of this study would be used to carry out research about the Virtual and Synthetic AtoN AIS System, and discuss the implementation issue with analogy to the Reversible Lanes.

References
(1) Tadashi Okano. A Study on the Methods to Analyze Vessel Traffic Data Obtained by Radar Observation. (March 2007)

Questions and Answers
FUKUTO JUNJI (National Maritime Research Institut):
Could you explain a minimum support system and its functions onboard to use the DTMS?
Tussedda El Hocine:
Thank you very much for your question, regarding the support system and its functions onboard, two cases can be found. First case where the ship satisfies the DTMS components, there is no need for additional
is already equipped with AIS, ENC ...etc and can receive and visualize the broadcasted new route. Second case where the ship doesn’t comply with the DTMS components, in this case a portable station (ex: PC based station) can be fitted onboard in such a way to receive and visualize the signal broadcasted by the AtoN Service Provider. The portable station can be designed according to local regulations and standards, and even can be limited to certain areas to prevent any interference with other standard shipborne equipment.