Macroscopic Traffic Analysis of Vessel Traffic Streams in Tokyo Bay

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1. Introduction

This analysis introduces a comprehensive macroscopic assessment of vessel streams in Tokyo Bay based on AIS (1) historical data obtained from the Tokyo University of Marine Science and Technology -hereafter referred to TUMSAT-Advanced Navigation System.

This analysis introduces a review of the traffic flow theory (2) and along with it, an application in the assessment of the vessel traffic streams; where vessel traffic streams are explored based on the fundamental diagrams theory (3,4) to investigate the existence of constraints related to free speed, jam density, and maximum flow rate within a designated area. The results of this work set up a framework which generates some additional constraints that should be taken into account when generating vessel traffic streams for simulation purposes based on developed traffic models.

2. Fundamental Diagram

The primary tool for graphically displaying information in the study of traffic flow is the fundamental diagram. Fundamental diagrams consist of three different graphs: mean speed-density $U(k)$, flow-density $Q(k)$, and mean speed-flow $U(q)$. The graphs are two-dimensional graphs, and all the graphs are inter-related by the fundamental relation equation as:

$$q = k \times u$$

where:

- $k$: Density expressed in Ship/NM.
- $q$: Flow Rate expressed in Ship/Hour.
- $u$: Mean Speed expressed in NM/Hour.

2.1 Speed-Density Diagram $U(k)$ [NM/Hour (Ship/NM)]

The speed-density relationship is linear with a negative slope; therefore, as the density increases, the speed of the traffic lane decreases. The line crosses the speed axis at free flow speed $u_f$, and the line crosses the density axis at jam density $k_j$ as shown in Fig.1.

2.2 Flow-Density Diagram $Q(k)$ [Ship/Hour (Ship/NM)]

The flow-density diagram is used to determine the traffic state of a traffic lane. The first ascending part is the free flow side of the curve, where the second descending part is the congested branch. The intersection of free flow and congested vectors is the apex of the curve and is considered as the free flow capacity of the traffic lane $q_e$, as shown in Fig.1.

2.3 Speed-Flow Diagram $U(q)$ [NM/Hour (Ship/Hour)]

The speed-flow diagrams are used to determine the speed at which the optimum flow occurs. The speed-flow curve also consists of two branches: the free flow and congested branches.

In the speed-flow diagram, the free flow branch is a horizontal line, which shows that the traffic lane is at free flow speed $u_f$ until reaching the optimum flow $u_c$. Once the optimum flow $u_c$ is reached, the diagram switches to the congested branch as shown in Fig.1.

3. Data and Area of Analysis

Tokyo Bay historical AIS data collected from the TUMSAT Advanced Navigation System, covering the period from the 11th of November 2011 to the 20th of November 2011, is used for this analysis.

Tokyo Bay congested traffic locations are reviewed based on the analysis of the AIS data. First, a plot of tracks of all vessels is drawn and then a visual assessment of the congested locations in the subject area is carried out. Based on the visual assessment of the congested locations in Tokyo Bay, three zones are selected for analysis namely:

1. Zone 1: delimited by Tokyo Bay Line in the south and Line “A” in the north as shown in Fig.2 (a).
2. Zone 2: delimited by the Uraga Suido Traffic Route (USTR) as shown in Fig.2 (b).
3. Zone 3: delimited, as shown in Fig.2 (c), as follows:
   - In the south by the USTR.
4. Results

Zone 1 unveiled an orderly and stable form of the fundamental diagram, where two states of traffic are observed, namely a free flow and a congested flow. After curve fitting and analysis, the traffic macroscopic variables are determined as follows: free speed \( u_f = 17.3 \text{ NM/Hour} \), capacity speed \( u_c = 7.6 \text{ NM/Hour} \), capacity density \( k_c = 5.8 \text{ Ship/NM} \), and maximum traffic flow \( q_c = 44 \text{ Ship/Hour} \). Regarding jam density \( k_j \), the results of Zone 1 confirmed the assumption that in normal traffic conditions, the jam state is never reached due to the nature the maritime traffic and the travelling medium where vessels cannot immediately stop on the water.

Zone 2 and Zone 3 analysis showed no constraints related to the traffic macroscopic variables, and only free flow traffic is observed. It is worth highlighting that in Zone 2, the speed restriction imposed by Tokyo MARTIS is confirmed through analyzed vessel traffic streams, and in Zone 3, most of vessels navigated with a speed less than 14 knots.

5. Conclusions

The associated analysis introduced in this paper sets a framework that could be used to assess the capacity of any designated traffic area without defining the constraints in advance, where vessel traffic streams are explored based on the fundamental diagrams theory to investigate the existence of constraints -other than limitations imposed by nature and restrictions imposed by port and traffic facilities specifications- that should be taken into account when generating vessel traffic streams for simulation purposes based on developed traffic models. By including the above constraints into the simulation traffic model, errors related to the volume of generated traffic will therefore be reduced. Nonetheless, it is important to keep in mind that some underlying constraints may have further implications in specific situations and so therefore, they should be examined case by case.

References