Analysis on the Spatial Distribution Characteristics of Maritime traffic profile in Western Taiwan Strait

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Abstract. The mathematical statistics and spatial analyses for merchant vessels navigating in Western Taiwan Strait are used to unravel potential spatial heterogeneity based on ship tracking records derived from China's coastal Automatic Identification System shore-based network from October 2011 to September 2012. Two maritime traffic profile’s indices, composition of vessels, weighted frequency of ship transits, are proposed. Based on the two indices, the most risky hotspots or areas in the Strait are detected by comparing spatial distribution of maritime traffic volume of fishing boat, container ship, crude oil tanker and all ships exclude fishing boats.

1. Introduction
The Strait of Taiwan is one of the most important shipping channels in the world, linking major economies such as China, Japan, South Korea, Southeast Asia, India, etc. It is about 200 nautical miles wide and is deep enough to permit all ships to pass through. However its navigable width of fairway narrows down to 15 nautical miles due to the effect of the Taiwan Bank in southern China, creating one of the world’s chokepoints. In the last decade maritime traffic on the Strait has increased drastically and represented as one of the world’s busiest shipping lane, therefore the navigational safety of vessel through the strait has attacks great attention from the maritime authorities [1] and other relevant stakeholders [2,3]. In maritime safety and security, the goal is to keep the seas safe and secure. The first step is monitoring and tracking of vessel. Considering the large numbers of ships, the many activities at sea, and the large areas have to be covered, computer-based support herewith is indispensable[4]. Nowadays a main source of information for vessel tracking is AIS-the Automatic Identification System. Due to the International Maritime Organization (IMO) imposed requirement for all ships, except the smallest ones, to install shipboard AIS which broadcasts messages with status data about vessel and its movements. China's Maritime Safety Administration (MSA) has built the world's biggest AIS shore-based network, in which data such as ship position, name, purpose, course and speed are automatic collected 24h hours per day primarily in Chinese coastal waters including western Taiwan Strait.

2. Composition of vessels sailing in the Strait of Taiwan
In consideration of the Strait under analysis, the composition of vessels is described using a large, fixed data set of sensory data: All AIS messages received in the 12 months between October 2011 and September 2012 along Western Taiwan Strait. This real-world data set was made available by MSA’s
AIS shore-based network. Such maritime authorities’ network is not given access to public, but similar data sets can be obtained by storing the streaming data from websites such as AIS Hub, MarineTraffic.com, and shipxy.com. What’s worth mentioning is that the AIS data do not fully reflect the existing traffic, mostly because of many small ships is not included, although a large number of fishing boats navigate in the Strait, especially in fishing season. We must bear in mind those fishing boats with small size maybe complicate the traffic to a certain degree leading to high risk of collision and grounding in the Strait. Another limitation lays in the incompleteness or error of AIS messages. For example some transmissions without geo-locations or some of them are out of the area of South China Sea. Thus, the total number of vessel recorded in the Strait may be smaller than the actual number by a certain extent.

The types of vessels and percentage share of the traffic in the Western Taiwan Strait are depicted in Figure 1. The diagram constitutes the results of 12 months of AIS transmission recordings, carried out from October 2011 and September 2012. In the diagram shown in Figure 1 the group labeled “other” consists of tugboats, research vessels, support vessel, and vessels for AIS transmission was not complete. An external database of vessel archive should be built to categorize vessels other than passenger ship and fishing boat, because the original AIS status indicating “cargo vessels” is a mixture of container carries, general cargo, Ro-Ro and bulk carries, moreover AIS status indicating “tankers” are include all the vessels carry crude oil, oil products, chemical and gas. The result firstly indicates that the majority of vessels involving in the Strait are fishing boats (17522) who account for 44% of total, which is a circumstantial evidence of the fact that many fishing boats from China are equipped with AIS. Secondly, close to half of “cargo vessels” specified in AIS status is made up of bulk carriers (7437). Finally to be denoted is that 2/3 of Tankers were carrying product oils.

![Figure 1. Types of vessels operating in Western Strait of Taiwan.](image)

As regards ship’s maximum draught and gross tonnages (GT) which are absent in AIS transmission records, a further operation of inner join should be done by merging AIS transmission records and online ship-archive from websites such as MarineTraffic.com, shipspotting.com. Afterward some ship variables such as length over all (Loa), Beam, Draught and Gross tonnage (GT) per vessel type were calculated, and the results are presented in Fig 2. Lables of vessel type (1~8) are rank-ordered in terms of variable’s median. For each variable (Loa, beam, draught, GT, etc.), box-and-whisker plots of irrespective of vessel type are drawn with widths proportional to the square-roots of the number of observations in the groups. The results indicate that crude oil tankers(label with 1) are always with most large dimension and gas tankers’ sizes(label with 5) are dispersed distinctly.

In order to view the distribution of ship variables (e.g. Loa) in details, we show a violin plot, which is a combination of a box plot and a kernel density plot. The results are depicted in Fig.3. Violin plot is used here to indicate a significant difference between tanker and others. The latter’s Loa is generally showed as a Centro-symmetric distribution. On the contrary, many tankers (except oil product tanker) are asymmetric distribution. For crude oil tankers, there is a distinct top-heavy, while
there is a clear bottom-heavy for chemical tankers, and gas tankers’ Loa is a complicated distribution which is a mixture of bottom-heavy and dual-hump one.

**Figure 2.** Comparison of ship Loa, beam, max draught, GT distributions by boxplot per vessel type sailing in the Taiwan Strait, based on AIS data between October 2011 and September 2012 (Lable of vessel type: 1-Crude oil tanker, 2-Container ship, 3-Bulk carrier, 4-Roro cargo ship, 5-Gas tanker, 6-Oil products tanker, 7-Chemical tanker, 8-General cargo ship).

**Figure 3.** Comparison of ship Loa’s distribution by Violin plots per vessel type sailing in the Taiwan Strait, based on AIS data between October 2011 and September 2012.

### 3. Spatial distribution of maritime traffic volume in the Strait of Taiwan

Vessel trajectories during 12 months are managed by three kind of time unit (sampling instant, stepping period and 24 hours) so as to built a three-level organizational framework. By compressing the volume of data and matching original vessel tracking message into spatial-temporal cube unit the retrieval efficiency increases significantly. By using ArcGIS platform of Geodatabase module, we have streamlined the acquisition, loading, filtering, display and analysis of raw AIS log files in ArcGIS [1].

Based on the above discussing of the vessels composition, a unified conversion relationship should
be built in advance so as to make the mixed traffic volume comparable for different fairway and transportation conditions. The vessel traffic volume over the Strait is described as weighted frequency of ship transits per cell (1Km*1Km) of lattice. The weighted frequency results from cumulates of the vessel flow equivalent factor based on the Loa (see Table 1)[5].

**Table 1.** Equivalent factor of different vessels based on the Loa.

| Level No. | Loa(m) | Equivalent factor |
|-----------|--------|-------------------|
| 1         | <30    | 0.25              |
| 2         | 30~50  | 0.50              |
| 3         | 50~90  | 1.00              |
| 4         | 90~115 | 1.18              |
| 5         | 115~135| 1.41              |
| 6         | 135~155| 1.70              |
| 7         | 155~170| 2.00              |
| 8         | 170~195| 2.25              |
| 9         | 195~215| 2.50              |
| 10        | 215~246| 3.00              |
| 11        | >246   | 4.00              |

**Figure 4.** Comparison of spatial distribution of ship movement weighted frequency in Western TaiwanStraits between October 2011 and September 2012. On left figure, all ships exclude fishing boats. On right figure, fishing boats only.

### 3.1. Ships exclude fishing boats

By dropping fishing boats, the result of merchant ships movement weighted frequency in Western TaiwanStraits during 12-months is shown as Fig.4 (Left).

Generally most of the high density of vessel traffic flow in Western Taiwan Strait dominantly distribute in coastwise route and show significant busy tendency, especially the narrow fairway of Bajiao Strait (label A in Fig.4’s left), Haitan Strait (label B in Fig.4’s left) and the junction of waterways in where vessels bound to and from Amoy (label C in Fig.4’s left). Their weighted frequencies are reach the peak value (>40,000).

Due to Taiwan Bank effect, there four distinct parallel 5-km-wide streams with weighted frequency above 8,000 in south of Taiwan Strait (label D1~D4 in Fig.4’s left) while the volumes of other area in open-sea are always dispersed and loose (weighted frequency <8,000).

Because there is a turn point (label E in Fig.4’s left) in 18Km south of Pingtan Island’s bottom for ships pass through Taiwan Strait, a distinct busy fairway is taking shape from the turn point to the area near east side of Wuqiu Island.

### 3.2. Fishing boats with small dimension
The sole category of fishing boats are selected to generated weighted frequency distribution chart which is shown in Fig.5. Compared with merchant ships (Fig.4.), fishing boats’ max weighted frequency is dramatically dropped because of their dimensions are always much small (see Fig.3). Bearing in mind that fishing boat accounts for 44% of total vessel compositions in the Strait (see Fig.1), these hotspots of fishing boat’ activities deserve more attentions, especially the coincident ones taking place in both Fig.4 and Fig.5. For example, the narrow fairway of Baijiao Strait(label A in Fig.5) and the junction of waterways in where vessels bound to and from Amoy Harbor (label C in Fig.5). Such areas appear to be high potential risk of collision involved merchant vessels with fishing boats.

![Figure 5. Comparison of Spatial distribution of Crude oil tankers and Container ships movement weighted frequncy in Western TaiwanStraits between October 2011 and September 2012.](image)

3.3. Vessels with huge dimension
As shown in Fig.3, both container ships and crude oil tankers are of huge dimension. Unlike most of other merchant ships, such as bulk and general cargo ship are inclined to occur in coastal route (for Fig.4’s right), vessels with huge dimension running through the Strait are prefer to take use of the straight lanes in open sea(Fig.5 ). For further research this kind of traffic should be surveyed. The reason maybe lies in the fact: there is a clear traffic with few ships occurs in open sea but involves the atrocious navigation conditions where only ships of high stability and well anti-overturing safety can overcome rip current, violent storms and wave. Container ships and crude oil tankers generally meet those restricted requirements and choose to sail on open sea at economic speed.

4. Conclusions and recommendations
In this study, we proposed two maritime traffic profile’s indices in the Strait of Taiwan: composition of vessels, weighted frequency of ship transits. The real-world data set of 12 months between October 2011 and September 2012 derived from MSA’s AIS shore-based network is applied in this study and managed by ArcGIS platform of Geodatabase module.

Composition of vessels is first being analysis: fishing boat, bulk carrier, general cargo ship, tanker and container ship account for 44%, 19%, 12%, 10% and 8% respectively. Half of tankers are carrying product oil and others tankers’ Loa distributions are non centro-symmetric. Both crude oil tanker and container ship are always with huge dimension while fishing boat is of min size.

Secondly weighted frequency calculated by equivalent factor of vessel’s Loa is applied to generate spatial distribution of maritime traffic volume of fishing boat, container ship, crude oil tanker and all ships exclude fishing boats.

Based on the two indices, the narrow fairway of Baijiao Strait and the junction of waterways in where vessels bound to and from Amoy Harbor are recognized and considered as the most risky hotspots in the Strait. Moreover there are distinct stress traffic flows near the west side of Taiwan Bank. The risk reduction methods should be prioritized being implemented in the above-mentioned area. The spatial pattern of traffic volume in western Taiwan Strait shows marked regional
differentiation characteristics, and it is necessary to introduce Traffic separation Scheme and Ship Reporting Systems for the sake of maritime traffic safety.

References

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