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Maritime Traffic Complexity Visualization: A New Method for Identification of High Opportunity and High Risk Areas

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ABSTRACT

A clear understanding of marine traffic complexity is vital for safe and efficient navigation inside ports (e.g., pilotage inside the basin). Built on statistical analysis of vessels' speed and course over ground extracted from satellite-based Automatic Identification System (AIS) data, an index of maritime traffic situation is developed in this research. After zoning the port basin, this index is calculated at each zone based on a combination of statistical measures (e.g., mean and standard deviation of speed and course over ground), in which vessels' class based on their size and targeted pier is also incorporated. The model could effectively increase the situational awareness by simple monitoring of navigation activities and reflecting improvements. This becomes possible by identification of high opportunity and high risk zones, i.e., those with high index value which call for operation modification which are far from and close to the infrastructures (e.g., breakwaters), respectively. To explore the model outcome, it is typically applied on the Rajaee port - the largest port of Iran located in the Persian Gulf - and output are discussed with port's maritime operators to analyze results. This resulted in identification of challenging zones for which pilotage plans could be improved. Also, it provided insight for better implementation of the basin which also could be considered in future development plans of the port.

1. Introduction

Considering the key factors when choosing among transportation modes as convenience, cost, speed, and safety, accordingly the most critical one; is the last one. As lose of safety may result in failure of transportation system. Despite the fact that safety is at the top of the agenda both for shipping lines and port authorities, it may be found that paces of safety improvement is rather slow. This is partly due to short memory, focus on consequences, problem complexity, unwillingness to change and selective focus [1].

A vessel generally experiences various traffic situations during its voyage and the main task of an officer on watch (OOW) during a navigational watch is to provide safety by avoiding hazards; e.g. collision; while taking it towards the destination. It becomes more challenging when encountering restricted regions with rapid traffic growth; for example in Yangtze River Over the last few decades, the throughput of ships in has increased rapidly due to the national development of the Middle and Western parts of China. Accidents such as collisions, ship groundings, contacts, oil-spills and fires occur repeatedly, often causing serious consequences [2].

Here come safety issues and safety management tools e.g. International Maritime Organization- Formal Safety Assessment guideline [3]. Traffic situation and vessels behavior have been studied for years; reasonably by introducing simplified models (e.g. [4], [5]). Information technology as a facilitator especially in recent years brings lots of data for a better understanding of such a complex environment. Today, Automatic Identification System (AIS) is mandatory for ships of 300 and 500 gross tonnage and upwards in international and national voyages, respectively (IMO 2002). AIS is among the most important marine traffic data recording tools. It boosts modeling as its usefulness has been proven in similar assessments overseas [6], [7].

Beside models investigating marine traffic to analyze a specific accident risk; e.g. collision, grounding or capsizing; there are researches in which AIS data have been implemented to represent a more clear view of marine traffic situation generally based on visualization models; using statistical measures to define randomness [8], [9]. This approach has gained attention through years; when compared with those discussing risk; as it simply brings lots of valuable information. For example, it has been used to visualize marine traffic situation and to recognize dangerous shipping areas in Xiamen Bay [6]. Jaicai [6] represented relative dangerous shipping area by incorporating the rate of ship turn, speed acceleration and ship counter into a new index. This model is useful to have a new point of view to understand traffic flows and accidents of maritime transportation as collision and grounding accidents.

General agreement for the exact meaning of randomness and its key factors cannot be easily found among scientists [10]. Most definitions represent some of its features and others give the human idea or outlook about randomness [11]. All in all, it is among the most important concepts bringing safety issues on the top of to-do list for decision makers. So an appropriate method should address randomness carefully while reduce complexity. In this paper randomness is defined as a quality of lacking a pattern or principle of maritime transportation in a specific area.

Situational awareness or in other words vigilance, is one of the most effective factors in many of maritime accident risk models [12], [13], [14]. This method is a unique tool for highlighting areas need more situational awareness. However this method cannot find the causes of full or low maritime situation. Using Bayesian network as a complementary tool besides this method can provide a holistic package for decision-makers to highlight zones with high maritime situation and causes of them.

This paper discusses traffic randomness with AIS data in Shahid Rajaee Port (as the most important flow gate of Iran during the past decade) by introducing various subset indexes and an overall index called *Index of Maritime Traffic Situation (IMTS)*. Here IMTS has been calculated in one terminal of the port using practical statistics by discretizing the port basin. Such an index should be kept minimized especially in zones close to the port infrastructures. So, its calculation and monitoring could result in higher safety and probably higher performance in port maritime operations.

This paper focuses especially on the problem of identification of high opportunity and high risk areas in restricted areas such as ports. So, section 1.1 discusses about traffic data and Shahid Rajaee port information. In Section 2 the paper methodology has been demonstrated. Methodology in this paper has 6 subsections which are port discretization, data categorization, filtering, modifying trajectories, calculating subset indexes and calculating IMTS. This section is a redesign of state-of-the-art models in AIS data visualization for finding maritime traffic situations (see [6]). The proposed Methodology is applied on data of Shahid Rajaee port (section 1.1) and the results are presented in section 3. In section 4 discussion over results has been described. Conclusions are summarized in section 5. References are shown in section 6.

1.1 Traffic data and port information

Shahid Rajaee port as the most important port of Iran has a unique geographical position, as it is at the north of the Hormoz strait (see Figure 1). Considering marine traffic of the region [15], it is a gate for Iran international trade while enhancing its transit corridors.

Figure 1. The location of Shahid Rajaee port in the Persian Gulf

Shahid Rajaee port has experienced the highest traffic from 2011 to 2013 and AIS data used in this study are one month representative of that period; form March 9 of 2011 to April 8 of 2011. Since this year was one of the busiest times of Rajaee port; this amount of data is relatively enough. Although more data will result in more relevant results. This data include vessels IMO number, positions, course over ground, and headings with ten seconds time steps. The assessment methodology is then applied on port general cargo terminal including wharfs number 9 to 20 (see Figure 2). Vessel size is an important factor, because similar sizes should have closer dynamics. Ships used in this paper are classified in Table 1 based on vessel Dead Weight Tonnage (DWT). Also available data is categorized from three different prospects as: vessel size, vessel called wharf and vessel direction (departure/ arrival) (Figure 5). Total number of ships is presented in Figure 3.

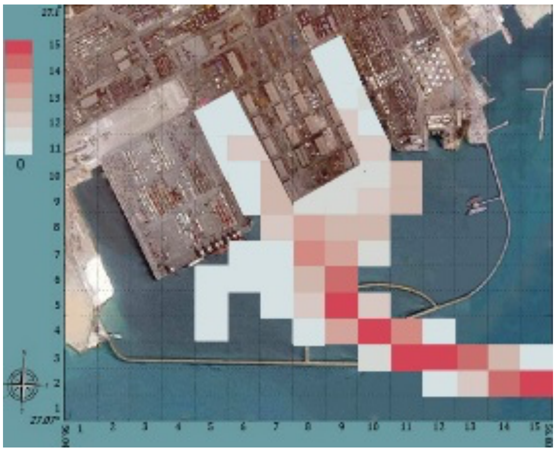

Figure 3. Total number of ships

Table 1. Classification of ships based on their DWT

Class A	Class B	Class C	Class D
<10000	10000-30000	30000-60000	60000-80000

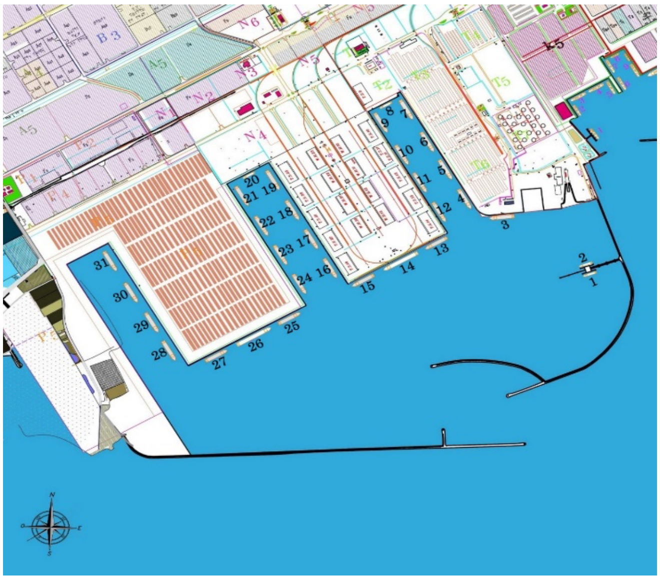

Figure 4. Master plan of Shahid Rajaee port

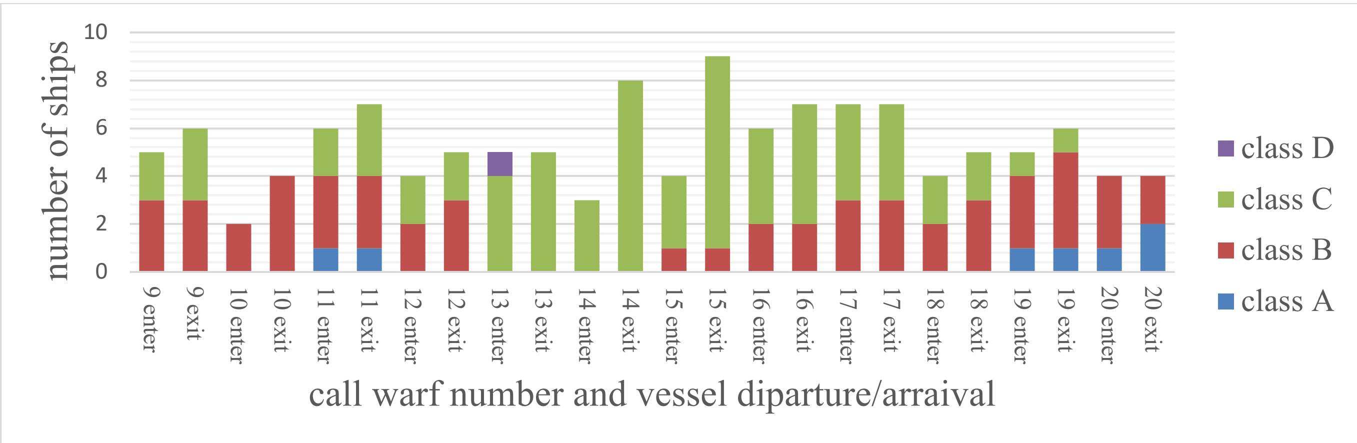

Figure 5. Maritime traffic data used in the analysis (class of ship, called wharf number and ship direction (departure/arrival))

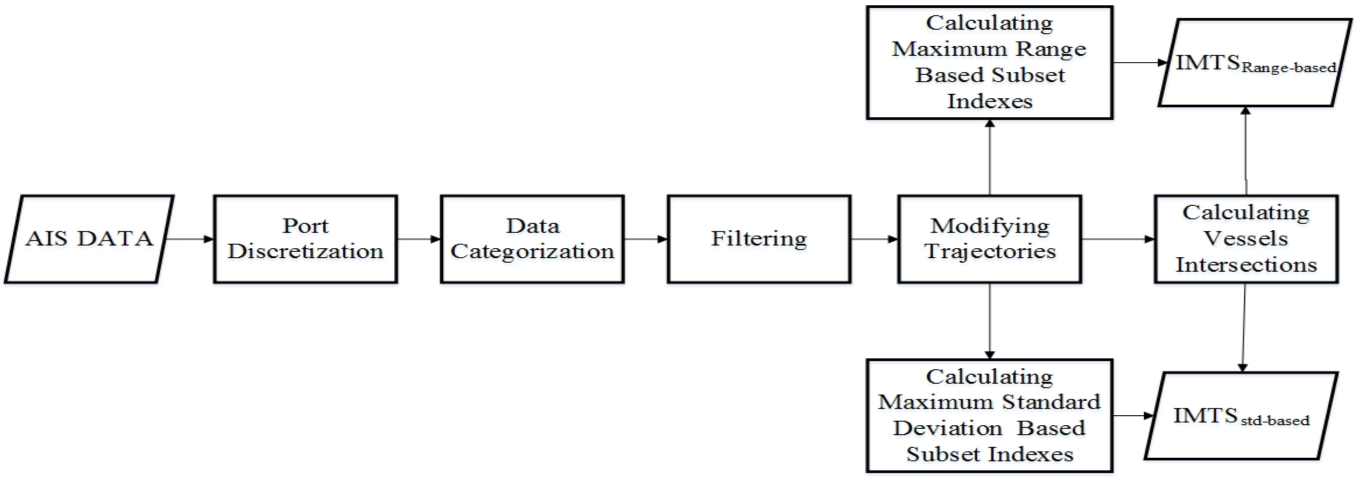

Figure 6. Procedure of calculating two IMTS; including preliminary steps

2. Methodology

Here, IMTS is introduced as an indicator of traffic situation based on two supplementary approaches using AIS data. The first approach is based on calculation of standard deviation of recorded values of vessel speed, and course over ground while in the second approach the range of recorded data is investigated. Here, the number of vessel trajectory intersections is included in both IMTS approaches. Background description is briefly presented in Figure 6. This study is evidence based. That means only AIS data is used and other sources such as questionnaires and expert elicitation have not been used in this study. The type of this research is quantitative applied and the utilized data have been gathered using the internet-connected shore-based stations at Shahid Rajaee Port and received from the Ports and Maritime Organization of Iran. As stated in section 1, the applied methodology to visualize marine traffic situation is based on [6] and more detailed descriptions are presented in the following subsections.

2.1 Port discretization

For the very first step, a port basin should be divided into discrete areas in which IMTS is calculated. Here, ShahidRajaee port basin has been typically discretized into 200*220 meters rectangles. A higher grid resolution could be used when discretizing a port, but mesh dimensions should be compatible with data resolution and ship size. In Shahid Rajaei port ships lengths were averagely 200 miters. In this paper by discretizing port area to 200*220 miters port discretized to 15*15 zones.

2.2 Data categorization

It is necessary to classify recorded data in order to extract appropriate index. AIS data should be categorized from three different prospects as: vessel size, vessel called wharf and vessel direction (see Figure 4). Vessel size is an important factor, as similar sizes should have closer dynamics. This classification is presented in Table 1 based on vessel Dead Weight Tonnage (DWT). Vessel called wharf is another important parameter, because vessels calling one wharf should have closer motion characteristics, as well. Finally, vessel direction; as inward or outward; should be considered when analyzing the data.

2.3 Filtering

Before any processing, the AIS data need cleaning; as it is called data pre-processing in terms of data mining. So, some thresholds should be defined and applied on AIS data. To minimize inherited flaw of AIS data appeared in collection or transmission process ships with irrational speed has been filtered while still ships in wharfs has been filtered otherwise this still ships can cause error in final results.

2.4 Modifying trajectories

One last issue before data processing is modification of ship trajectories. As mentioned in previous paragraph, since there is often some errors in AIS data, filtering is inevitable. Practically this means some records of AIS data should be removed. Therefore data should be modified. The data used in this paper has time step of 10 seconds. Which gives a high resolution. So in order to modifying trajectories, positions have been adjoined linearly. But in case data have a high time step e.g. 30 minutes or more, it is better to modify trajectories with a nonlinear method. There are several methods for this purpose. For example in AIShandler software, ship trajectory could be modified by PAEK and Bezie Interpolations, as they have been considered in this study.

2.5 Calculating subset indexes

In this paper IMTS is calculated using two statistical approaches which here are called standard deviation based IMTS (IMTSstd-based) and maximum range based IMTS (IMTSrange-based). Here range mean maximum difference between speed and COG of used data. In both approaches IMTS consists of three subset indexes. The *normalized number of trajectory intersections index* as the common index in both approaches is one of them. Here intersections mean, confluence of trajectories of ships regardless of time. Normalization formula is presented in eq.4 In order to calculate *normalized number of trajectory intersections index,* by using modified trajectories in MATLAB software trajectory of ships in one month has been drawn and number of their intersections in each zone has been calculated. All intersections are counted at each zone irrespective of vessel size, vessel called wharf or vessel direction. This index could simply highlight zones with higher traffic density and probably higher importance.

For $IMTS_{std\text{-}based}$, normalized standard deviation of speed ($std(speed)$), normalized standard deviation of course over ground (($std(cog)$), and mean of both of these data are also calculated at each zone. Before these calculations, ships data are classified based on vessel size, vessel called wharf and vessel direction. Then the following equations are used to combine different categories output to yield one standard deviation subset index [15]:

$$deviance = \sum_{i=1}^{g} (n)_{i-1} {s_i}^2 + \sum_{i=1}^{g} n_i (\bar{x_i} - \bar{x})^2 \quad (1)$$

$$std = \sqrt{\frac{1}{N_{total} - 1} deviance} \quad (2)$$

$$mean = \frac{\sum_{i=1}^{g} n_i * \bar{x}_i}{\sum_{i}^{g} n_i} \quad (3)$$

$$normalized\ value = \frac{y - y_{min}}{y_{max} - y_{min}} \quad (4)$$

Where, g is the number of categories which are supposed to be combined, n_i stands for number of members of class i, s_i is standard deviation of class i and $\bar{x_i}$ is mean of the data in class i, $\bar{x}$ is mean of the means of all classes and N_{total} is total number of members of all classes. y is the calculated values of speed, cog and intersection in each zone. Here, a class (class i) is formed by ships of the same size, the same called wharf and the same destination (direction).

In a similar way, normalized maximum range of speed and cog of vessels are calculated and used in $IMTS_{range\text{-}based}$. While there is not a direct relationship between standard deviation and range, these two measures should be used efficiently to clarify randomness.

2.6 Calculating IMTS

In order to reach a holistic view on maritime traffic situation, all subset indexes; as discussed in section 3.5; should be incorporated into one index as IMTS in each statistical approach.
Here, $IMTS_{std\text{-}based}$ and $IMTS_{range\text{-}based}$ are calculated as below:

$$IMTS_{std-based} = \alpha.std(cog) + \beta.std(speed) + \lambda.intersections \quad (5)$$

$$IMTS_{range-based} = a.range(cog) + b.range(speed) + c.intersections \quad (6)$$

Where α, β, γ, a, b, and c are tuning coefficients which could be adjusted due to the weight of their related factors. Where there is no data available to calibrate these values, equal values are used for these coefficients [5].

3. Results

In Figure 8 std(speed) is presented by contour plot while zones including higher 10% of range(speed); between 2.70 knots to 3 knots; are also hatched. Figure 7 presents mean of speed of ships. The maximum value of std(speed)=1.55 knots happened in zone number (8,7), while mean of speed of data in this zone in relatively low. Here, the first number indicates the horizontal axis and the second one indicates the vertical axis. The maximum value of std(speed) is not coincident with zone number (8,5) where the maximum value of range(speed)=3 knots is occurred. According to Figure 3 number of ships passed from zones (8,5) and (8,7) are relatively medium.

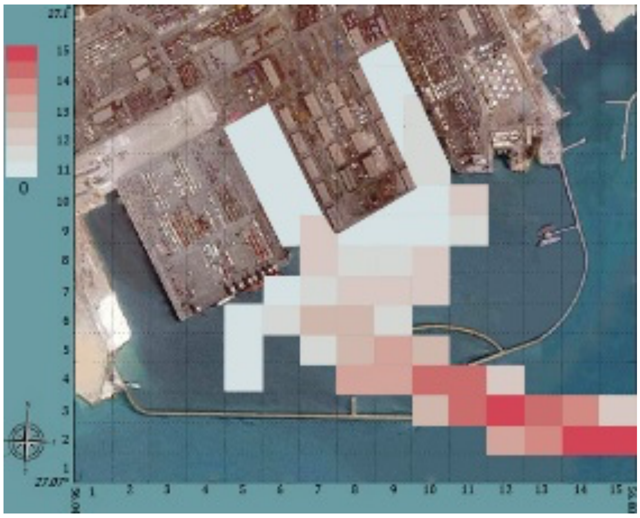

Figure 7. Mean of speed of ships

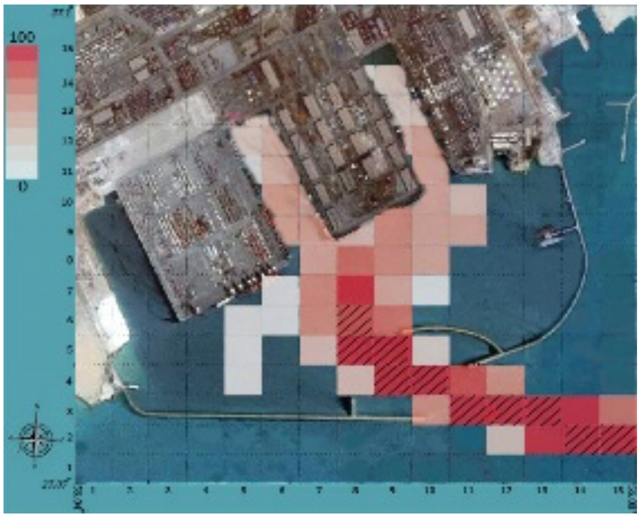

Figure 8. Normalized standard deviation of speed; where hatched zones represent those with high speed range

In Figure 10 std(cog) is contour plotted and zones including higher 10% of range(cog) are also hatched. Figure 11 presents mean of cog of ships. The maximum value of std(cog)=9.65° happened in zone number (8,7). The maximum value of range(cog)=21.30 happened in zone number (8,5). In

Figure 9 mean of cog of ships is presented. The highest values of standard deviation and range of heading, have been experienced in different zones same as the case of standard deviation and range of speed. And mean of cog in these zones is relatively low as well as case of speed. There are zones like (11,10) where both std(cog) and range(cog) are high.

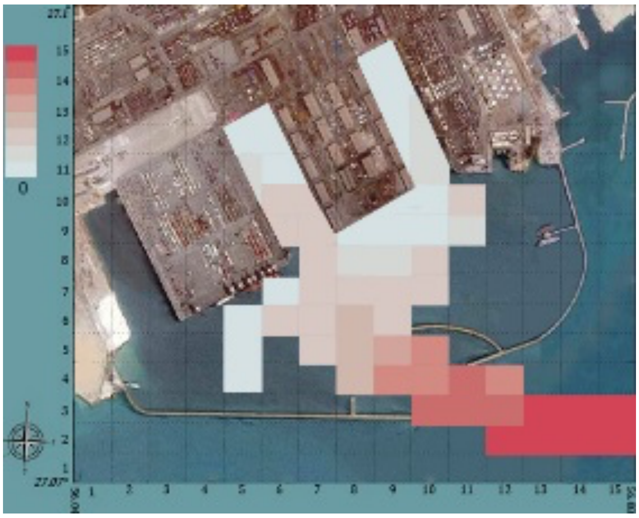

Figure 9. Mean of cog of ships

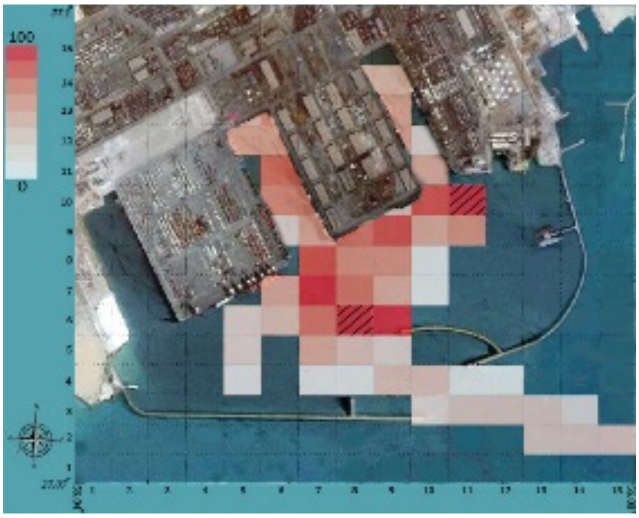

Figure 10. Normalized standard deviation of cog; where hatched zones represent those with high cog range

Number of intersections has been normalized and shown in Figure 11. Here, a clear pattern is obvious as could be expected.

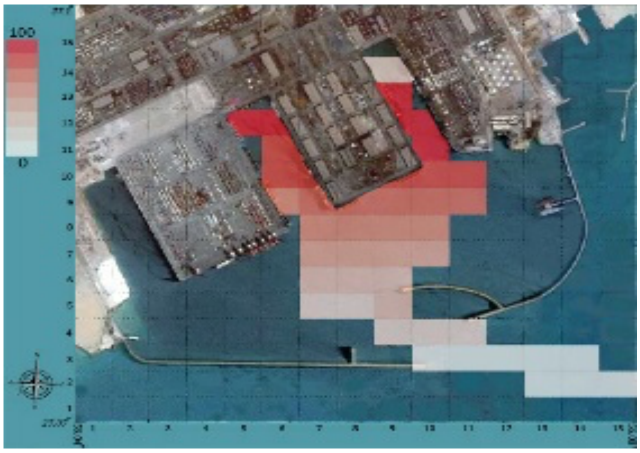

Figure 10. Normalized number of intersections

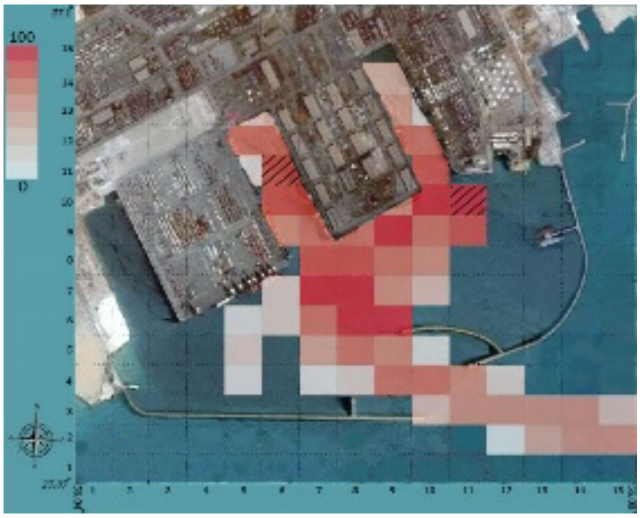

Figure 11. Contour plot of normalized $IMTS_{std\text{-}based}$; where hatched zones represent those with high $IMTS_{range\text{-}based}$

As discussed earlier, in order to have a comprehensive view over port maritime operations, IMTS has been calculated within two statistical approaches. In Figure 8, IMTSstd-based is presented by contour plot while zones including higher 10% of IMTSrange-based are also hatched.

4. Discussion

The need to upgrade the time window of the ship's mooring has been well illustrated by this model. Since zones (6,6), (5,6), (5,5), and (5,4) represent a ship used that area to berth for one day and night. And according to Shahid Rajaee development plan in third development phase this area will be used for container ships transportation and the ports traffic in this zones will be denser. Therefore as illustrated in Fig.12 the area of line number 3 can't be used as a station for any ship during its loading and unloading. Although such an area is necessary according to port managers, the left area of line 1 can be used for such intentions.

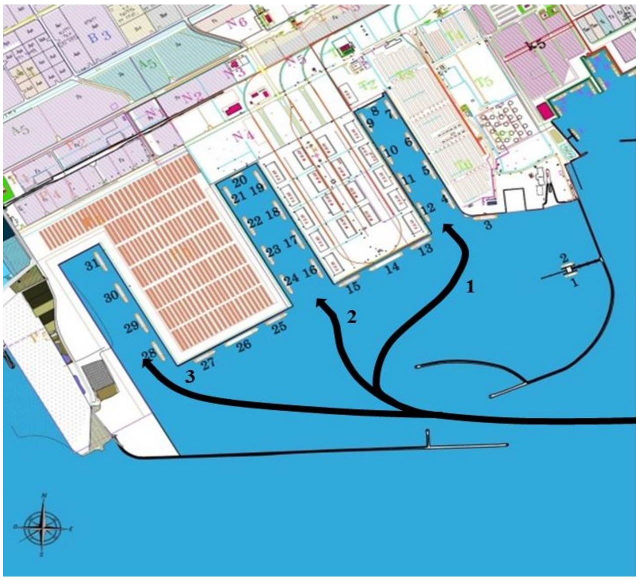

Fig.12. ships paths to different parts of port

Minimizing $std(speed)$ near the port approach channel as well as fixed structures at the port entrance is very important for port authorities, because high randomness in speed increases risk of contact with structures accidents in related zones. This should be considered urgently in Shahid Rajaee port as $std(speed)$ is high in aforementioned zones. This is evident in Figure 8. Where $std(speed)$ is presented by contour plot while zones including higher 10% of $range(speed)$; between 2.7 knots to 3 knots; are also hatched. Here range is maximum and minimum values of speed of ships in a zone. The maximum value of $std(speed) = 1.55\ knots$ happened in zone number (8,7). The maximum value of $std(speed)$ is not coincident with zone number (8,5) where the maximum value of $range(speed) = 3\ knots$ is occurred.

Maximum value of $std(speed)$ and $range(speed)$ have happened at different zones. Accordingly both of these zones need more attention. As one of them might be misleading. These two indexes are relatively higher inside the port when compared with those outside while mean of speed of ships inside the port is lower than than those outside the port. This might not be good news for port authorities.

In the meantime, it is obvious that minimizing $std(speed)$ and $range(speed)$ near the port entrance will result in more smooth and safe operation inside the port.

High randomness in ships cog is another source of risk intensification as well as reducing maritime operation performances of thug boats in a port basin. In Figure 10 $std(cog)$ is contour plotted and zones including higher 10% of $range(cog)$ are hatched. It is obvious that, a clear variation pattern could not be found when checking $std(cog)$ (see Figure 10.) while this was almost the case for $std(speed)$ (see Figure 8). In other words, although $std(cog)$ is low in the port approach channel; which clearly shows an appropriate pilotage; but it experiences a peak in zone (8,6). This is where ships should generally change their way toward their destination. This shows in this zone ships experienced rapid changes in their maneuvers. So traffic details in this zone has been reviewed. As traffic is typically shown for a class of vessels; same DWT and same target wharf; in Figure 13, dissimilarity among ships dynamics marked by black lines clearly has the main role in increase of $std(cog)$. So, ships have not been treated consistently; probably due to the lack of concrete pilotage instructions. For example, two vessels of one class have been treated differently in this zone. Besides, existence of one ship with rapid changes in its manner; as shown by the red line in this figure; resulted in high $range(cog)$.

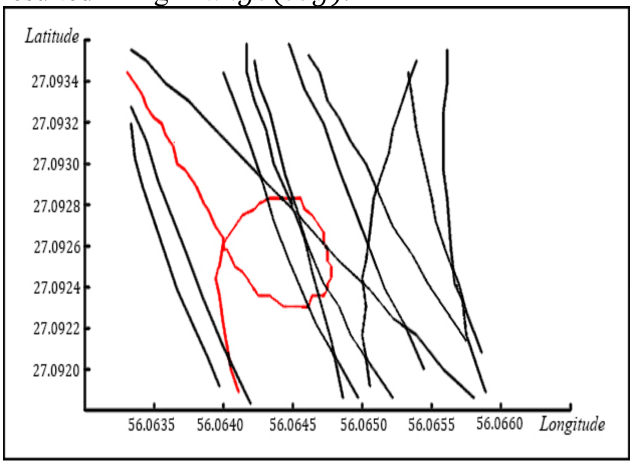

Fig. 13. Marine traffic in zone (8,6) for a class of ships; (black line): dissimilar traffic patterns, (red line): rapid change

Besides, $std(cog)$ is relatively high in zones (9,9) and (10,10) which is not good news considering their proximity to port works. As typically shown by the yellow line in Fig. 14, internal movement have been experienced among wharves which might be due to multi-type cargo stowage plan as well as port weak time window management according to discussions with pilots of thug boats of Shahid Rajaee port. Such movements result in high randomness as they are not generally acceptable. Another probable reason for such high value of $std(cog)$ is ship berthing from port or starboard as typically shown by white lines and red lines in Fig. 14. Such disordered berthing could be a potential danger for the port safety as ships would not follow a similar un-berthing pattern expected from a specific wharf. Here, it could be also recognized that a ship marked by red dotted line in Fig. 14 has been treated completely different from the other ones. This might be due to some temporary situation in port traffic handling. It should be noted that we have not investigated the sources of such disruptions in port maritime performance deeply since the main concern of our research is to visualize maritime traffic and highlight the problems. Therefore, more detailed studies are required to find the causes and propose the solutions.

Baesd on the results, the highest values of standard deviation and range of cog, have been experienced in different zones same as the case of standard deviation and range of speed. There are zones like (11,10) where both $std(cog)$ and $range(cog)$ are high. As there might be vessels departing wharfs number 9, 10, 11, and 12 which move astern and then revolve in this zone to move bow toward port entrance (see the red line in Fig. 15). Besides, this zone is where ships should change their heading toward port entrance (see the yellow lines in Fig. 15). This turbulence in zone (11,10) should be treated very carefully as it is very close to the port bunkering wharf; placed at its north-side. Besides, the zone is on the way of container vessels calling wharves number 4, 5, 6 and 7. So, it is better to have lower amount of such maneuver in this zone.

So, both dissimilar traffic patterns and existence of rapid changes play important role in high randomness in Shahid Rajaei port.

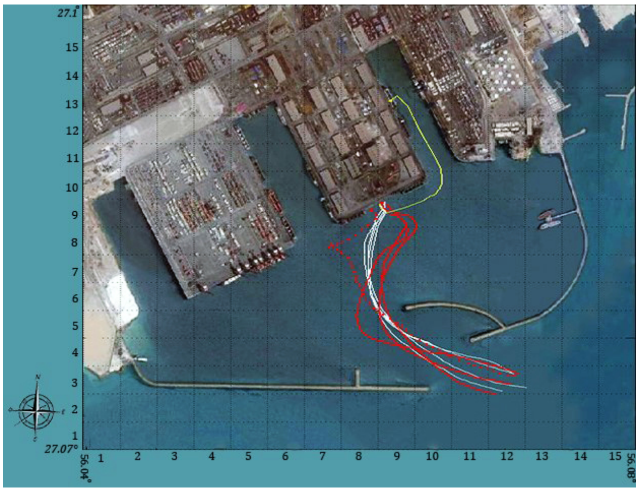

Figure 14. Typical movement of ships to wharf number 14; (yellow line): ship with internal movement, (white line): ship berthing by starboard, (red line): ship berthing by port, (dotted red line): ship with unexpected movement

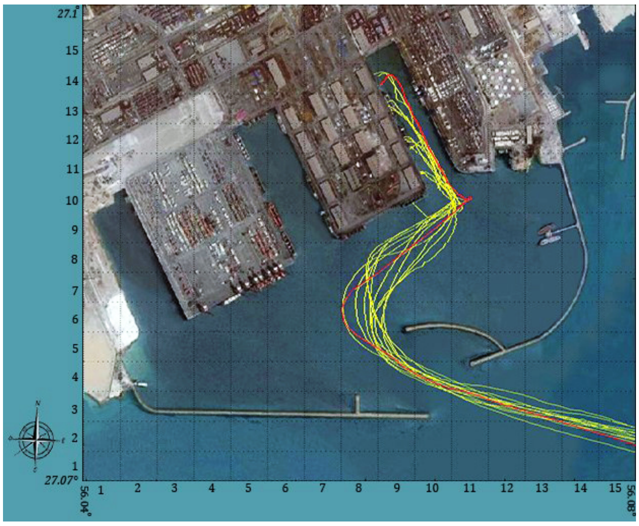

Figure 15. Trajectory of ships departing the port and crossing zone (11,10)

IMTS do not follow a regular pattern as subset indexes of speed and cog did not follow a regular pattern (see Figure 11). In zone (6,11) $IMTS_{range\text{-}based}$ is maximum while it was not so in $range(cog)$ and $range(speed)$. This reveals the importance of considering the three subset indexes in one package as included in IMTS. Zones with high $IMTS_{std\text{-}based}$ and $IMTS_{range\text{-}based}$ are more complicated and consequently need more attention from maritime authorities as well as shipping lines for a safe navigation passage.

5. Conclusions

In this paper, a novel AIS data visualization model has been presented base on calculation of IMTS. It is shown that $IMTS_{std\text{-}based}$ and $IMTS_{range\text{-}based}$ are both important as they evaluate different aspects of randomness. So they should be considered together when discussing port operation performance or port safety.

In order to have the best practice from safety and efficiency perspectives; it is also possible to calibrate coefficients of IMTS to highlight importance of different parameters included in IMTS. All and all, the simple introduced IMTS worth calculation while it provides a good time-history of improvements and disorders.

It was shown in this article, the time window of arrival and departure of the ship and the management of general cargo in hinterland of Shahid Rajaei port can be upgraded and implemented more regularly. In this regard, the next steps of this article can be dedicated to these issues. However, since these cases are mainly related to human factors, it is very important to use the right tools. For this reason, writers and other interested parties can consider the use of Bayesian network in port management as a serious option.

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