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A quantitative approach for delineating principal fairways of ship passages through a strait

Jinhai Chen [a,b,*], Feng Lu [a,c,*], Guojun Peng [b]

[a] State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] Marine Navigation & Pilot Technology Research Centre, Navigation College, Jimei University, Xiamen 361021, China
[c] Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing 210023, China

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ABSTRACT

Seamen usually select popular routes according to navigational and hydrographical characteristics when passing through a strait with congested traffic. In order to minimise the possibility of collisions, Principal Fairways (PFs) are commonly used by sailors. It is essential to delineate PFs quantitatively and objectively for designing or refining routing measures. In this paper, a space use method found in habitat evaluation of wildlife is applied to extract PFs of ship passages through a strait. Compared with existing methods, the proposed method helps to identify cumulative activity patterns for ship groups derived from mass ship trajectories, and provides a clearer interpretation of shifting space-use patterns within strait corridors. Moreover, it gives a better insight for directional and seasonal factor for PFs in straits. Finally, this novel method is used to extract PFs in western Taiwan Strait and its adjacent sea. The results indicate that the proposed method is helpful to identify gaps between current ship routing system plan and cumulative activity patterns recognised by real ship trajectories.

1. Introduction

There were various traditional observations to extract shipping routes due to the application of Voice Radio Communication and Radar in tracking vessel in the 20th century (Schwehr, 2011). Thousands of European antecedent voyages across the oceans were extracted from ship logbooks in the age of sail (Können and Koek, 2005); Radar data were implemented to create ship routing system of Dover Strait (Johnson, 1973); Global commercial ship lanes were abstracted by using of locations reported by 3374 voluntary observing ships in a period of 12 months (Halpern et al., 2008). However, traditional records were just sparse samples and shipping traffic was not captured by these data. Fortunately, nearly all seagoing merchant ships and passenger ships are required to carry an Automatic Identification System (AIS) according to current mandates released by the International Maritime Organisation (IMO). The wide deployment of AIS allows ships be tracked in 24 h per day. Meanwhile the emerging technology of space-based AIS provides a global coverage of the maritime domain including in the open sea (Guillarme and Lerouvreur, 2013). Recent advances in ship tracking and telemetry technology help to collect the movement tracks more efficiently and accurately. The ship tracks have increased tremendously, and these advances have been accompanied by the development of new methods, which serve for marine transport planning especially in crowed shipping areas, such as straits.

Straits are shortcuts between two large water bodies. These passageways generally host large amounts of traffic volume with various directions. Thus, the risk of collision between ships is higher in straits than in other waterways (Klanac et al., 2010; Qu et al., 2011). This congest situation will become even worse with the massive increase in global shipping. To minimise the possibility of collisions in ships passage straits, states bordering certain congested straits may create routing systems to separate vessels, control crossing and meeting situations. Developing ship routing schemes in congested straits have become an important topic in maritime transport, especially the straits heavily used for international navigation, such as the Dover Strait (Johnson, 1973; Squire,

Abbreviations: AIS, automatic identification system; ANR, application nautical range; CCSRSP, China's Coastal Ships Routing System Plan; CMSA, China Maritime Safety Administration; ER, exponential regression; EF, equivalent factor; IMO, International Maritime Organisation; KDE, kernel density estimation; IV, isopleths volume; LCP, least cost path; LOA, length over all; PA, precautionary area; PF, principal fairway; SD, standard deviation; SNR, specific nautical range; SUD, shipping utilisation distribution; TSS, traffic separation schemes; UD, utilisation distribution; WF, weighted frequency

* Corresponding authors at: State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences and Natural Reso urces Research, Chinese Academy of Sciences, Beijing 100049, China. Tel.: +86 10 64888966; fax: +86 10 64889630.

E-mail addresses: jhchen@jmu.edu.cn (J. Chen), luf@lreis.ac.cn (F. Lu), penggj1314@126.com (G. Peng).

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2003) the Istanbul Strait (Aydogdu et al., 2012), and the Malacca Strait (Qu et al., 2011; Zaman et al., 2014). However, only 15 straits throughout the world have implemented Traffic Separation Schemes (TSS) approved by the IMO (UKHO, 2012). Vessels are required to follow certain sea lanes in those TSS areas. There are improvements for other straits on keeping ship traffic flows in good order. The selection and development of routing systems are the responsibility of maritime administrators. Within this context, such administrators should consider various factors, including the knowledge of Principal Fairways (PFs), existing navigation aids, the state of hydrographic surveys in the area and accepted standards of routing (IMO, 2003). There are always attractive and popular routes accessible to sailors with respect to navigational and hydrographical characteristics through a given strait. PFs are the water areas commonly used by sailors and have a large traffic volume, which are believed to be the most economical sailing method. Thus they are empirically significant in recommended routes for sailors. In previous work involved ship routing system on straits (Aydogdu et al., 2012), PFs (so-called main traffic flows) are subjectively selected based on mariners' experience, which is not quantitatively repeatable.

Perceiving how mobile objects move about space is a fundamental research question in Geographic Information Science, and there are many quantitative methods for analyzing movement data (Long and Nelson, 2012). Of these, Origin-Destination matrices is arguably the most straightforward method to represent routes in a network (Christiansen et al., 2013). It is also accepted in maritime/ocean engineering literature. For example, Kaluza et al. (2010) extracted 490,517 routes linking 36,351 distinct pairs of Origin-Destination in annual global AIS database to represent the global shipping network. Eight main Origin-Destinations were defined as main routes in the Istanbul Strait (Aydogdu et al., 2012). However the method of Origin-Destination matrices only concerns the origin and destination of each movement but ignores the actual trajectories. One of the potential solution is Route Topology Modelling appliance, where routes are abstracted into a topology model composed of discrete legs, junctions, nodes and their associated attributions like urban road network (Oltmann, 2014). However, the maritime environment remains an open space where navigation in any direction is allowed. Thus, the shipping network is rather different from the road network, which is known a priori to construct corresponding urban road topology (Tsatcha et al., 2014).

It is important to keep in mind that in maritime/ocean engineering communities, the goal of sea-lanes identification is to preserve navigational safety rather than to port accessibility(Christiansen et al., 2013). This is the reason why a manual strategy is adopted in fairways selection (Fowler and Sørgård, 2000; Montewka et al., 2012). van Dorp and Merrick (2011) applied an automated filtering process to clean noisy routes and define ideal trajectories in simulator. Tzavella and Ulmke (2014) proposed a semi-automatic sea-lane extraction approach with particle filtering. Apart from manual, supervised and semi-automatic approach, there are other various unsupervised strategies of fairway extraction, such as image processing technique (Aarsæther and Moan, 2009), shared nearest neighbour algorithm (Santos et al., 2012), density-based clustering of ships' waypoints algorithm (Arguedas et al., 2014a,b; Pallotta et al., 2014, 2013). Those existing methods of ship route extraction just concern waypoints, then give a continuous line or labeled (clustered) track-lines set. Their results were representative of a sea-lane, but ignore the boundary and utilisation distribution of principal fairways. In terms of maritime corridors identification on the whole, it is clear that dedicated efforts should be directed to increase scientific understanding of PFs.

There is a wide variety of maritime quantitative methods focus on ship-ship collision risk assessment (Li et al., 2012). The fundamental principles consist of finding a number of vessel conflicts in nautical traffic data (e.g. AIS, Radar) and assigning a probability to each of these conflicts. Many maritime accident risk model have been proposed, such as blind navigation collision candidates methods (Fowler and Sørgård, 2000; Goerlandt and Kujala, 2011; Montewka et al., 2012; Otto et al., 2002), traffic simulation methods (Asmara et al., 2014; Blokus-Roszkowska and Smolarek, 2012; Goerlandt et al., 2012; van Dorp and Merrick, 2011), traffic indices methods (Qu et al., 2011; Suman et al., 2012), Bayesian networks methods (Montewka et al., 2014), fuzzy methods (Sahin and Senol, 2015; Zaman et al., 2014), evolutionary algorithms (Szlapczynski, 2013), Ship Domain methods (Montewka et al., 2012). Among them, Ship Domain methods were widely applied in the geometrical probability of encounter after the pioneering works of Fujii and Shiobara (1971), Goodwin (1975).

There are various definition of Ship Domain, such as a description based on characteristics of vessels engaged in emergency maneuvering (Montewka et al., 2012; Zhang et al., 2012), an empirical domain based on AIS data (Hansen et al., 2013), a dynamic quaternion model with fuzzy boundaries (Wang, 2013). Meanwhile SD could be regarded as a factor for determining the width of a fairway (Jensen et al., 2013). However, there is still highly uncertain in the definition of Ship Domain and vessel encounter (Goerlandt and Kujala, 2014; Sormunen et al., 2014).

The existing methods only provided low-level contextual information of PFs, such as waypoints through track-lines, and the direction on each leg. It indicates a need for next generation of quantitative method to discover high-level knowledge concerning capturing PFs boundaries and understanding changes in PFs over time. As such, we seek to answer the question: how to delineate the boundary of PFs (i.e. strait corridors) and recognise the importance of variations in the intensity of space-use within a PF.

This paper is outlined as follows. The background and related work in ship movement tracks analysis are introduced in Section 1. Section 2 provides a brief overview of fundamental concepts of space-us, then introduces the material of AIS and bathymetric dataset. Section 3 elaborates the proposed method for delineating PFs. Section 4 illustrates how the space-use technique performance for its application on Taiwan Strait, and shows how to utilise the proposed method to identify gaps between current routing system plan and the extracted PFs. The application is used to guide a practical discussion of the usefulness of the space-use technique for PFs analysis in Section 5. Finally, Section 6 draws the conclusion and provides some suggestions for future research applications of space-use techniques in maritime engineering.

2. Criteria and material

As discussed above, there are few algorithms about quantitative delineating PFs available in the scientific literature. PFs were always subjectively selected in previous routing scheme planning. In order to get a further understanding of PFs, nautical science maybe have a try to embrace other disciplines such as ecology and geography. So we develop a cross-disciplinary application of ecological methods found in habitat use of wild animal.

2.1. Criteria related to space use

To facilitate cross-disciplinary learning, we take a try to view PFs from the perspective of ecological discipline, especially review how habitat use is perceived in the wildlife ecology and obtain a new knowledge of PFs.

2.1.1. The base criteria of habitat use

Historically, animal space-use patterns have been described using a series of concepts, such as Utilisation Distribution, Home