Probability Estimation and Implication of Piracy Using a Tangible Method

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ABSTRACT
It is an important and difficult problem to calculate the probability of encountering pirates for a trip. This paper proposes a tangible method to estimate the probability based on the historical data from International Maritime Bureau (IMB) and the United Nations Conference on Trade and Development (UNCTAD). The tangible method consists of two parts. At first, it is assumed that the probability is equal everywhere in the sea. The average probability of piracy is estimated. Then, an adjusting coefficient is proposed to revise the probability of piracy in each trip. The adjusting coefficient of each trip is related to the average number of piracy in every grid which is defined in Geographic Information System (GIS) and come across by the trip. Finally, a numerical example of a trip from Shanghai to the Republic of Kenya is used to illustrate the application of the proposed method. The results show the average probability of encountering pirates in 2012 is 0.0216% when a ship travels a thousand miles. The adjusted probability of encountering pirates is estimated to be 1.62%.

Keywords: Piracy, Probability, Estimation, GIS
1. INTRODUCTION
Piracy has been an international non-traditional safety issue of maritime transportation. Piracy leads to loss of about 25 billion US dollars every year (1). Furthermore, their geographical scope of activity is extending. Piracy and armed robbery against ships remain a real and ever-present danger to those who use the seas for peaceful purposes (2). Huang (2012) took piracy as one of the three main factors that threaten China’s maritime safety (3). Li also regarded piracy as an important risk factor when assessing risk of crude oil transportation (4, 5). The increase in the number, ferocity and geographical scope of incidents of piracy and armed robbery against ships, too often resulting in death, injury or the kidnapping of seafarers, has compelled the United Nations, regional bodies, governments, military forces, shipping companies, ship operators and ships' crews, to work together in order to rid the world of the threat posed by piracy.

Figure 1 shows that piracy cases alternate high and low spot (6). It is stressed that piracy is a problem that will never disappear or get eradicated completely (7). In 2012, the number of piracy decreased a lot. But nobody can guarantee that the number of piracy will decrease continuously. From the changing tendency, the number of piracy every year always increases after several years’ decrease. From Figure 1, it seems that there is a general upward trend, but with cycles.

![The number of global piracy cases from 1994 to 2012.](source: IMB Piracy and Armed Robbery Against Ship-2012 Annual Report)

Considering that pirates have been a threat to maritime safety for a long time, researchers have done much work on it. The literatures about piracy can be mainly classified into three categories: the cause of piracy, the impact of piracy, and measures to anti-piracy. Esher et al. (2010) used agent models and statistical design of
experiments to gain insight into how meteorological and oceanographic factors can be used to dynamically predict piracy risks for commercial shipping (8). Bowden et al. assessed the economic costs of maritime piracy, including the direct financial costs of piracy, such as ransoms, insurance premiums, the costs of re-routing to avoid piracy regions, deterrent security equipment, naval forces, piracy prosecutions, and anti-piracy organizations, and the secondary (macroeconomic) costs of piracy, such as: effects on regional trade, fishing and oil industries, food price inflation, and reduced foreign revenue (9). Fu et al. (2010) modeled shipping demands and competition in the Far East-Europe container liner shipping service to investigate the economic welfare loss effects by Somali piracy due to reduced volumes of trade and shipping, as well as efficiency loss due to geographical re-routing of shipping networks which would be otherwise uneconomical (10). The various counter piracy missions and the shipping industry have worked together to produce a series of best management practices (BMPs) (BMP4, 2011) that will deter pirates (11). Percy (2013) analyzed five obstacles to end Somali piracy (12). Bulkeley (2003) examines the potential for the emergence of a multilateral maritime regime in East Asia founded on regional cooperation to reduce maritime piracy (13). Somali pirates have always been studied as the case because piracy attacks have been most concentrated in Somali region (8, 14, 15, 16).

However, there are rare researches into the probability of piracy. There exist some researches into the probability of accidents in maritime transportation. These researches may be the references of study into the probability of piracy. Qu (2012) estimated that only not more than 0.005% vessels are involved in accidents with different severities in the Singapore Strait (17). But it only considered the accidents in the strait. As for a trip through the strait, it may be involved in accident out of the strait. Dobbins adapted a GIS-based highway planning traffic assignment model to estimate the casualty rate in American coast using both accidents data and ship trip data (18). Weng (2012) estimated vessel collision frequency in the Singapore Strait using Automatic Identification System (AIS) data (19). Huang et al. (2013) analyzed the spatial distribution of maritime accidents using GIS (20). As for piracy, there are reports about the number of piracy while it is difficult to get the data about trips in each area. So it is difficult to calculate the occurring probability of piracy.

Without the traffic flow data in each shipping lane, this paper tries to estimate the probability of piracy using a tangible method. At first, it is assumed that there is equal probability of piracy everywhere in the sea. In this way, the average probability of piracy in the whole sea is calculated. But it is obvious that different areas have different probability of piracy. In order to solve this problem, a coefficient is calculated by the number of piracy occurred in the areas the trip comes across to adjust the result. The remainder of the paper is structured as follows: Section 2 describes the piracy statistic data and seaborne trade data. Next, the probability estimation and implication model is presented in Section 3. Section 4 carries out a numerical example to illustrate the application of the proposed method. Finally,
discussions and conclusions are provided in Section 5.

2. PIRACY STATISTIC DATA AND SEABORNE TRADE DATA

The ICC International Maritime Bureau Piracy Reporting Centre

The ICC International Maritime Bureau (IMB) is a specialized division of the International Chamber Of Commerce (ICC). The IMB is a non-profit organization, established in 1981 to act as a focal point in the fight against all types of maritime crime and malpractice. IMB’s main task is to protect the integrity of international trade by seeking out fraud and malpractice. For over 25 years, it has used industry knowledge and access to a large number of well-placed contacts around the world to do this: identifying and investigating frauds, spotting new criminal methods and trends, and highlighting other threats to trade.

One of the IMB’s principal areas of expertise is in the suppression of piracy. Concerned at the alarming growth in the phenomenon, this led to the creation of the IMB Piracy Reporting Centre in 1992. The Centre is based in Kuala Lumpur, Malaysia. It maintains a round-the-clock watch on the world’s shipping lanes, reporting pirate attacks to local law enforcement and issuing warnings about piracy hotspots to shipping. IMB Piracy Reporting Centre writes a report about pirate attacks every year. Its annual report has been regarded as the most reliable report about pirate attacks. According to ICC-IMB annual report, piracy is divided into four categories as shown in Table 1. Figure 2 shows the percentage of different types of piracy in 2012. Among the four kinds of piracy, hijack is the only one which causes huge loss to ship owners.

It is assumed that:

Rate of Hijack (ROH) = The number of hijack/ total piracy cases.

It can be calculated from Table 2 that ROH is around 10% from year 2009 to 2012. This means pirates don’t have dominate advantages over ships. Many piracy attempts are failed. If the ship owners remain on their guard, piracy cases of hijack can be decreased.

According to data from IMB Piracy Reporting Center, Coggins (2012) introduced Maritime Piracy Data (MPD), a dataset dedicated to understanding the nature, dynamics, and causes of contemporary piracy and armed robbery against ships (27). He summarized the piracy data with coordinate data from 2000 to 2009.
TABLE 1  Category of Piracy Cases

<table>
<thead>
<tr>
<th>Type</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hijack</td>
<td>Pirates boarded and taken control of a vessel against the crews will</td>
</tr>
<tr>
<td>Boarded</td>
<td>Pirates boarded but failed to take control of a vessel against the crews will</td>
</tr>
<tr>
<td>Fired upon</td>
<td>Pirates fired upon the ship but failed to board the ship</td>
</tr>
<tr>
<td>Attempted boarding</td>
<td>Pirates attempted to board the ship</td>
</tr>
</tbody>
</table>

FIGURE 2  Pie chart of different types of piracy cases in 2012.

TABLE 2  Rate of Hijack in all the Piracy Cases from 2009 to 2012

<table>
<thead>
<tr>
<th>Type</th>
<th>Year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total attacks</td>
<td></td>
<td>410</td>
<td>445</td>
<td>439</td>
<td>297</td>
</tr>
<tr>
<td>Hijacked ships</td>
<td></td>
<td>49</td>
<td>53</td>
<td>45</td>
<td>28</td>
</tr>
<tr>
<td>Ratio of Hijacked</td>
<td></td>
<td>12%</td>
<td>12%</td>
<td>10%</td>
<td>9%</td>
</tr>
</tbody>
</table>

United Nations Conference on Trade and Development:

Review of Maritime Transportation 2012

The Review of Maritime Transportation is a recurrent publication prepared by the United Nations Conference on Trade and Development (UNCTAD) secretariat since 1968 with the aim of fostering the transparency of maritime markets and analyzing relevant development. The review would include the international seaborne trade, the
world fleet, freight rates and maritime transport costs, port, and legal issues and regulations. *Review of Maritime Transportation* 2012 gives a comprehensive overview of the situation of maritime transportation. It shows the number of ships in the market, the total deadweight tons of these ships and the total ton miles of seaborne trade (22). Specific data needed in this paper is extracted and shown in Table 3.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>World total capacity (dwt)</td>
<td>1,518,109,503</td>
</tr>
<tr>
<td>The number of vessels</td>
<td>46,901</td>
</tr>
<tr>
<td>The world seaborne trade in cargo millions of ton-miles</td>
<td>44,540,000</td>
</tr>
</tbody>
</table>

3. PROBABILITY ESTIMATION AND IMPLICATION MODEL

In this section, the probability estimation and implication model is built based on the frequency probability theory. At first, the number of piracy is acquired. Then, the number of piracy is divided by the traffic flow in each shipping lane. Because the traffic flow in each shipping lane is unknown, we propose a tangible method to estimate the probability of piracy in each shipping trip under conditions without traffic flow data. The tangible method consists of two steps. The first step is to calculate the average probability of piracy in a thousand ship-miles assuming that the probability of encountering piracy is equal everywhere in the sea. The other step is to adjust the average probability using a coefficient. The coefficient is determined by the spatial distribution of historical piracy and calculated with the aid of GIS.

As the premise of estimation, some assumptions are made.

1. The number of piracy reported by IMB is considered to be the actual number of piracy.
2. Every ship travels the same shipping miles.
3. The probability of encountering piracy is equal everywhere in the sea.

The procedure of estimating the probability of piracy is presented as follows:

1. Step 1: estimate the number of piracy in the studied time period;
2. Step 2: estimate the average size of ships in this period;
3. Step 3: count the ship-miles all the ships traveled in this period;
4. Step 4: calculate the average probability of piracy in a thousand ship-miles;
5. Step 5: calculate the adjusting coefficient of a trip;
6. Step 6: calculate the probability of the trip.

3.1. The Number of Piracy

The first step of probability estimation is to acquire the number of piracy served as the nominator. The number of piracy from ICC IMB is used. As stated in the annual report of IMB in 2012, the number of piracy in 2012 is 297. The ICC IMB reports on Somali piracy have been criticized in different opinions (14); one view states that there is a certain amount of over reporting of piracy incidents due to the Best...
Management Practice (BMP) developed by the shipping industry (11), which recommends that seafarers report any suspicious approaches in the vicinity. The other view claims of underreporting in the ICC IMB statistics because some ship operators fear that their illegal activity will be disclosed if they report piracy activity (23). However, the data reported by the IMB are consistent with other global reports and have been widely adopted by international institutions like the IMO because no alternative source can resolve the potential underreporting problem (24).

3.2. Estimation of Average Probability in Certain Ship-Miles

For the convenience of estimation, it is supposed that there are N ships in the market and notations are given as follows.

Notations:

\( i \): ship \( i, 1 \leq i \leq N \);

\( D_i \): the distance in miles that ship \( i \) travels;

\( S_i \): the size of ship \( i \) in dwt;

\( \bar{S} \): the average size of ships in dwt taking travel distance of ships as the weight;

\( Q \): true demand for shipping service taking distance into consideration in ton miles.

\( M \): the number of piracy;

\( P_a \): the average probability of encountering piracy in a thousand ship miles;

\( Q/\bar{S} \): if there were only one ship in the market, how many miles the ship travels to have the same effect of all the present ships;

\( Q \) is the total transportation volume of all ships. It is calculated in Eq. (1) below:

\[
Q = \sum_{i=1}^{N} S_i \times D_i \tag{1}
\]

\( \bar{S} \) is calculated as the following equation.

\[
\bar{S} = \frac{\sum_{i=1}^{N} S_i \times D_i}{\sum_{i=1}^{N} D_i} = \frac{Q}{\sum_{i=1}^{N} D_i} \tag{2}
\]

In Eq. (2), it is difficult to get the data of \( D_i \). According to assumption 2, every ship travels the same shipping miles.

\[
D_i = D_j, \quad 1 \leq i \leq N, \quad 1 \leq j \leq N \tag{3}
\]

Then, \( \bar{S} \) can be estimated using the following formulation:

\[
\bar{S} = \frac{\sum_{j=1}^{N} S_j}{N} \tag{4}
\]

\( Q/\bar{S} \) is the miles that if there were only one ship in the market, the ship travels to have the same effect of all the present ships. The average probability \( P_a \) can
be calculated as follows:

\[ P_a = \frac{M}{Q/S} \]  

(5)

### 3.3. Adjusting Coefficient

In chapter 3.2, in order to be convenient to calculate the probability of piracy, it is assumed that the probability of encountering piracy is equal everywhere in the sea. However, in reality, it is not always the case. In order to solve this problem, a coefficient is advised to adjust the probability calculated by the model in 3.2. This coefficient is determined by the number of piracy occurred along the trip.

In order to calculate the coefficient, GIS is used as a technical tool. It is an effective and unique tool for spatial analysis and provides visualization of geographic data. The aim of GIS is to provide a spatial framework in which we can model our world, make reasonable usage of our resources, and support our decision for sustainable development of the environment. Generally, GIS comprises three components. Firstly, GIS has a spatial database which contains data models (like features, grid, and topology) used to describe the physical world. Similar objects are grouped into layers and information about each object is maintained in a relational database or file. Objects are typically represented in vector format, such as points, lines or polygons. Aerial images, such as satellite photos, can also be used in most GIS packages and included in the database. Secondly, a GIS presents its data via an intelligent map. This map can also be regarded as a visualization of the database. Finally, GIS typically provides a spatial process toolbox that enables complex analysis of database objects based on their spatial locations using the current analysis module or through software written by the user or third parties. GIS has been widely used in highway planning, network analysis, and other applications.

Arcgis 10 is used as our software platform. In Arcgis 10, the world map is divided into 18*36 (648) grids. Then the number of piracy in each grid can be calculated. A map was divided into 18*36 fishnets by the *creating fishnet* tool in ArcToolbox. A new layer named *fishnet* was created. Then, the *piracy* layer was connected to the *fishnet* layer, creating a new layer named *fishnet_SpatialJoin*. In the layer *fishnet_SpatialJoin*, there was a data field named *Joined_Count*, which represented the number of piracy in a particular fishnet. Finally, the number of piracy in each grid is shown in Figure 3, which is the basis of calculating coefficient.

The coefficient of each trip is calculated according to the number of historical piracy in the grids the trip comes across. Here, the piracy data from 2000 to 2009 is used to calculate the coefficient.

According to the piracy data from 2000 to 2009, the average number in a grid is 3413/648=5.3.

As for a trip j, the grid it comes across can be found. Then the average number of piracy in each grid it comes across is calculated, regarded as \( \bar{N} \).

If \( k_j \) stands for the coefficient of trip j, it is define:
Then, the adjusted $P$ of trip $j$, $P_{a,j}$ can be calculated as
\[ P_{a,j} = P_a \times K_j \] (7)
As for trip $j$, the real probability of this trip, $P_j$, can be calculated as:
\[ P_j = P_{a,j} \times L_j \] (8)
Where $L_j$ represents the length of the trip.

4. CASE STUDY
In order to illustrate the application of the proposed method, a trip from Shanghai to the Republic of Kenya is taken as an example, labeled as trip sh-k. The year 2012 is selected as calculation time period. According to ICC IMB Piracy and Armed Robbery Against Ships-2012 Annual Report, the number of piracy in 2012 is 297. As recorded in Review of Maritime Transportation, the number of ships in the market is 46901, the total deadweight tonnage is 1,518,109,503 and the world seaborne trade in cargo ton-miles is estimated as 44,540,000,000 thousand of ton-miles. Then, the average size of all ships is calculated according to Eq. (4).
\[
\bar{S} = \frac{\sum_{i=1}^{n} S_i}{N} = 32368 \text{ dwt}
\]
\[
\frac{Q}{S} = \frac{44,540,000,000}{32,368} = 1,376,000 \text{ thousand miles}
\]
\[
P_a = \frac{M}{Q/S} = \frac{279}{1,376,000} = 2.16 \times 10^{-4} \text{ (thousand miles)}^{-1}
\]

It means if a ship travels one thousand miles, the probability of encountering piracy is \(2.16 \times 10^{-4}\).

It is 5536 miles from Shanghai to the Republic of Kenya. Based on the result in Figure 3, by calculating the number of piracy in the grids come across by this trip in Figure 4, the average number of piracy occurred in each grid of the trip is 71.5.

From Eq. (6), the coefficient of the trip is calculated.

\[
K_{sh-k} = \frac{71.5}{5.3} = 13.6
\]

Combining Eq. (7) and (8), the probability of this trip, \(P_{sh-k}\), is estimated.

\[
P_{sh-k} = P_a \times K_{sh-k} \times L_{sh-k} = 2.16 \times 10^{-4} \times 13.6 \times 5536 \times 10^{-3} = 1.62\%
\]

This trip comes across the Somali area and the Malacca Strait, which are two hot spots of piracy. So the probability seems a little big. Probability of other trips can be calculated in the same way.

**FIGURE 4 Example of a trip from Shanghai to the Republic of Kenya.**

5. **CONCLUSIONS**

This paper proposes a tangible method to estimate the probability of piracy under the condition without the traffic flow data in each shipping lane. Even though it is not precise, it is a meaningful foundation to quantify the probability of piracy, especially when the exact data is difficult to get. From the result, it can be seen that piracy is a threat with small probability. It could be a meaningful step for shipping companies to assess risk of piracy.

This paper may have some limitations. For example, the number of piracy may be underreported or overreported. Furthermore, the data used to calculate the adjusted
coefficient should be renewed to the year 2013. Because of lack of time, this renewing work is delayed. Other factors, influencing the probability of a ship encountering pirates, for example, the velocity of ship, the height of ship, safeguard of the ship, are not considered in this research.

Future work can be done in three aspects. One is looking for the traffic flow data in each shipping lane. If the traffic flow data can be found, the probability of piracy can be calculated more easily and more precisely. Then, the consequence of piracy incidents can be considered to make a comprehensive risk analysis. Finally, the method needs to be verified in practice.

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