Rough Set Approach to Marine Cargo Risk Analysis

Jasmine Siu Lee LAM
Division of Infrastructure Systems and Maritime Studies, School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
Email: sllam@ntu.edu.sg

Abstract:
Considering the complication of shipping techniques, high mobility of cargoes and poor condition and uncertainty during the voyage, there are numerous risks in the transportation process. With the burgeoning of shipping volumes, the occurrence of accidents and disruptive events could bring huge losses. Despite of regulatory control such as the establishment of International Safety Management (ISM) Code, the rate of shipping accidents has not been reduced to the desired levels. Therefore, it is paramount to establish an effective risk quantification and management mechanism for shipping companies and to improve risk control process in order to cover the various components of the operating system. This paper provides a systematic and practical rough-set-based marine cargo risk analysis approach with the aim to find out the influential risk factors. Together with industry inputs, a comprehensive set of risk evaluation indicators considering various factors affecting shipping operations is developed. The study uses Rough Set method to classify and judge the safety attributes related to marine cargo and vessel. The method which is based on intelligent knowledge acquisition provides an innovative way for evaluating marine cargo risk. As illustrated by an example of a shipping company, we are able to calculate the significance of each factor and the relative risk exposure based on the original data without assigning the weight subjectively. Risk mitigation strategies can be formulated accordingly.

Key words: marine cargo, shipping, risk analysis, safety, rough set

1. Introduction
Acting as trade facilitator, maritime transport plays a significant role in the contemporary world economy. However, shipping and marine cargo have been challenged by considerable increase in maritime risks. Events such as natural catastrophe, ship collision and piracy continue to appear in news headlines. Over the last decades, there has been an increase in the number of natural hazards and catastrophic events (EMDAT, 2012). Munich Re reported that the overall earthquakes and weather-related catastrophes in 2011 is the costliest year ever, recorded a total natural catastrophe losses at about US$380 billion and total insured losses of US$ 105 billion (Munich Re, 2012). A recent example is the Tohoku earthquake and tsunami in March 2011 which damaged Japanese seaports and marine cargoes. In terms of man-made incidents, piracy crisis in the Gulf of Aden, off the coast of Somalia, and in the wider Indian Ocean, has worsened since 2008 (MSC, 2012). Despite of regulatory control such as the establishment of International Safety Management (ISM) Code, the rate of shipping accidents has not been reduced to the desired levels (Celik et al, 2010; Knapp and Franses, 2010).

Considering the complication of shipping techniques, high mobility of cargoes and poor condition and uncertainty during the voyage, there are numerous risks in the transportation process. With the burgeoning of shipping volumes, the occurrence of accidents and disruptive events could bring huge losses. Furthermore, while precautionary measures such as insurance coverage could be adopted, hidden risks such as business interruption and loss of reputation that operators fail to identify will accumulate with the
expansion in scale of business. Shipping companies could suffer from significant losses and financial difficulty. Therefore, it is paramount to establish an effective risk quantification and management mechanism for shipping companies and to improve risk control process in order to cover the various components of the operating system. Building a risk assessment system, identifying and evaluating risks before hazards happen, dividing the risk level, conducting a feasibility study and formulating a risk mitigation plan (Manuj and Mentzer, 2008) is the major process to reduce the risks of shipping industry’s stakeholders. The first and foremost point is, however, how to scientifically identify the core indicators that lead to shipping risk exposure among the numerous and complex factors, which has not been addressed in existing literature.

This paper, from a risk management perspective, focusing on the issue of marine cargo risk analysis, provides a systematic and practical rough-set-based approach with the aim to find out the influential risk factors in the shipping process. The study uses Rough Set method to classify and judge the safety attributes related to marine cargo and vessel. The focal point of this paper is to quantify the importance degree of each factor, and to build a mathematical model that comprehensively evaluates the risk exposure of marine cargo. After a literature review, the paper will present the methodology and the set of marine cargo risk evaluation indicators. Then the modeling process will be demonstrated by an example of a shipping company. The results and implications will be discussed thereafter.

2. Literature Review

2.1 Shipping risk analysis
A number of studies considered ships’ technical features as causes of shipping risks. Roberts and Marlow (2002) conducted descriptive statistical analysis of the structural failure of bulk carriers based on Lloyd’s of London casualty records over 1963–1996. Improvement in ship design such as strengthening bulkheads was suggested to reduce vessel and cargo damage. Celik (2008) analysed the design-based deficiencies in shipboard systems by referring to experimental surveys and ship deficiency reports. A shipyard-centered information network on monitoring design-based failures was proposed. Focusing on engineering perspective, Wang et al. (2002) developed a model to measure the structural performance of a ship in an accident. Some other scholars focused on navigation environment (Judson and Shortreed, 1999; MacDonald, 1999). Toffoli et al. (2005) conducted an investigation of shipping accidents particularly reported as being due to bad weather conditions. Based on frequency and severity of accidents, Hu et al (2007) performed a formal safety assessment by quantifying risks in ship navigation, particularly harbor pilotage. The human factor is another main concern investigated in the literature. Fatigue, stress, teamwork, communication and safety culture were found to be important human factors influencing maritime safety (Hetherington et al., 2006). The analysis of accidents in container ships showed that safety management practices, safety training and job safety are the most significant factors (Lu and Tsai, 2008). Celik and Cebi (2009) conducted a comprehensive study applying the Fuzzy Analytical Hierarchy Process (AHP) method for human factors analysis and classification. Skill-based errors, personnel factors such as coordination and communication, as well as shortfalls in the execution of organizational processes as root causes were the key factors.

While the literature provides good references on shipping risks, the major limitation of the above studies is that they mainly focused on one kind of factor. Few efforts have been extended to conduct risk analysis considering multiple factors. Antão and Guedes Soares (2008) analysed a chain of events leading to shipping accidents. The associated causal factors for ocean-going commercial vessels and high-speed crafts were examined. Human error, daily operation, ship equipment, management and resources parameters were included. Nevertheless, only descriptive statistics were presented which would not be able assess the significance of the factors. More rigorous analysis included the work done by Ventikos and Psarafitis (2004) which developed the event-decision network and related it with International Maritime Organization (IMO)’s formal safety assessment for oil spill accidents. Major factors considered were
human, vessels and environmental conditions. The ship, crew’s qualification, the environment and meteorology were included in Balmat and Lafont’s (2009) study on individual ship risk factor using fuzzy logic evaluation. Centered on shipping accident investigation, Celik et al (2010) combined the effects of organizational faults and shipboard technical system failures in their modeling approach using a fuzzy extended fault tree analysis. However, these studies did not directly relate to cargo damage/loss and the associated risk analysis. Skjong and Guedes Soares (2008) suggested that there is an urgent need for improvements in methodological approaches in order to enhance shipping safety. This paper contributes by addressing these gaps in the existing literature.

2.2. Rough set theory
This paper studies marine cargo risk in the international shipping setting, which faces high uncertainty and dynamism in a multi-facet environment. After a comprehensive literature review, we propose the Rough Set approach firstly introduced by Z. Pawlak (Pawlak, 1982) as a new solution tool, which has successful applications in data mining, prediction, control, pattern recognition and classification, mechanism learning, and decision analysis and support in other domains, such as finance (Dimitras et al, 1999), marketing (Kumar et al, 2005), human resource management (Chien and Chen, 2007), image processing (Wojcik, 1994) and engineering (Shen et al, 2000). The method classifies the study objects into similarity classes containing objects that are indiscernible, i.e. possess the same properties. The classification features form the basic concepts of knowledge about the subject matter.

Rough set theory (RST), which is based on knowledge acquisition and discovery, would have brilliant application prospect in the research topic. In many practical systems, there are various degrees of uncertainty, especially in the data collection process which often contains inaccurate and missing data. RST is a suitable mathematical tool to deal with vagueness and uncertainty (Pawlak, 1995). Considering marine cargo transportation, the most important task is to ensure safe and timely cargo arrival at the port of destination. Based on this concern, evaluating the elements along the shipping path directly and the root cause of risks would be the most appropriate approach. The condition of marine cargo transportation is usually dynamic and hard to predict, which leads to difficulty in finding pre-requisite knowledge. A major advantage of RST is that the weight of the factors is not assigned subjectively like what is done in AHP method. Also, RST does not require any preliminary or additional information about the data, unlike requiring grade of membership or the value of possibility in fuzzy set theory used in previous maritime risk studies (Grzymala-Busse, 1988; Pawlak and Slowinski, 1994; Kusiak, 2001).

3. Research Methodology
The research process is divided into three stages as shown in figure 1. Stage 1 involves secondary research in which literature review has been conducted to understand the state of the existing scholarly work related to the topic of interest. Also, various sources such as company annual reports, trade journals, databases and the internet were consulted for collecting data and information especially on shipping incidents. The deliverable of the first stage is a tentative list of indicators for marine cargo risk assessment. The second stage is primary research with the main objective to verify the proposed indicators and data collection. Five semi-structured interviews were carried out in 2011 to gather opinion and information from the industry. The interviews were targeted at the management personnel of two shipping companies and two insurance companies which are the most relevant for the study topic. Shipping companies represent a natural choice since they are carriers of marine cargoes and are in charge of the voyage. The companies have domain knowledge in shipping management including the handling of the associated marine cargo risks. As for insurance companies, they are professional organisations in managing risks by underwriting insurance policies, thus being able to provide relevant information and opinion on the subject matter. A maritime professional who has worked in various sectors in the maritime industry for over 30 years was also consulted for a neutral and balanced view. Though the interviews were performed in Singapore, the organisations involved are all international entities serving a wide coverage of the global
market. The organisations are among the world’s largest in their respective industry sector. The interview setting was not limited to local specificity. The interviewees have given information and opinion on the indicators for marine cargo risk analysis. Minor adjustment was made to the list of indicators according to the interview outcome of Stage 2. Then Stage 3 involves modeling by rough set approach. Through a numerical example, RST is applied for obtaining the importance degree of each indicator in quantitative characterization, that is, to obtain the weight vector of each indicator. Finally, based on the output of the evaluation model, result interpretation and judgment on risk mitigation as well as validation are demonstrated. Details of the rough set approach will be presented later in section 5.

Figure 1: Research Process

4. Marine Cargo Risk Evaluation Indicators

This study takes reference from the literature and incident records as explained above for developing a comprehensive set of indicators for marine cargo risk evaluation throughout the shipping process. The evaluation aims to fully reflect the various factors and their significance. Shipping is a system, where shipping companies, ship, cargo, crew, port and waterway transport system are crucial to maintain the normal operation of shipping (Frankel, 1999). Any problems in an element or any errors arising from the interaction among the elements may lead to accidents. External factors such as weather conditions should also be included in the risk evaluation (Toffiò et al., 2005). The risk evaluation indicators representing the sources of risks will be elaborated below.

4.1 Human factor (R1)

Human factor mainly refers to seafarers as they are the personnel directly controlling the shipping process. Several researches (UK P&I 1999; Portela, 2005) reflected that human error caused 60% to 80% of all the maritime accidents. The human factor can be divided into two categories as below.

1) Knowledge and Skill (R11)

Seafarers have to go through specialized training and the level of technical quality is fundamental. With more advanced marine technology, the requirement on crew’s knowledge and skills has become more complicated (Celik and Cebi, 2009). Safety training programmes can help to reduce vessel accidents (Lu and Tsai, 2008). Such training should cover both accident preventive measures and handling techniques should any incidents occur. Crew should be equipped with knowledge and skills adequate for manning the specific ship type and cargo operations.

2) Safety Consciousness (R12)

Fatigue, stress, teamwork, communication and safety culture are important human factors influencing maritime safety (Hetherington et al., 2006). Safety consciousness is an appropriate indicator to reflect these issues since the crew’s awareness in risk-prone acts and circumstances is directly related to shipping safety level (Griffin and Neal, 2000).
4.2 Vessel (R_2)
Sub-standard or aging vessel is one of the risk sources. The ship’s status is closely related to maintenance and duration of usage. In general, the overall situation of the ship can be reflected from its technical condition.

1) Age of the Ship (R_{21})
With hull structural strength declining due to corrosion and physical damage sustained during cargo operations, the ability to resist wave, the operational reliability of ship equipment and the intact rate drop (Lloyd’s, 1991; Wang et al., 2002). According to the accident statistics taken by DNV (DNV, 2001), vessels aged 15 years or above account for 86% of total loss in ship accidents, meaning that ship's age has great impact on the stability and strength of vessels.

2) Hull and Machinery (R_{22})
The condition of the vessel’s hull and machinery also directly determines shipping operations. Cargo vessels should satisfy the requirements of hold configuration, fireproofing and waterproofing condition, electronic facilities, communication facilities, lightning conductors and cargo gear (FAA, 2000); otherwise problems will appear and may lead to vessel capsized.

4.3 Cargo (R_3)
The cargo itself is responsible for marine cargo and shipping risks.

1) Cargo Attributes (R_{31})
Cargo attribute evaluation should focus on whether the goods are dangerous. Dangerous goods should be specially taken care of to avoid explosion and other serious consequences. As such, shipping operations should obey the International Maritime Dangerous Goods Code (IMDG) published by IMO (Gold, 1986; IMO, 2011).

2) Cargo Stacking (R_{32})
In recent years, a large number of marine accidents investigation showed that a considerable proportion of the incidents is directly or indirectly due to the movement of goods carried. According to MAIB statistics in 2010 (MAIB, 2010), out of 12 cases occurred in merchant ships, six happened due to stacking issue which directly reflects the problem of staking system. Hence, cargo staking should obey the SOLAS Convention and have cargo securing certification approved by the authorities.

4.4 Port (R_4)
Ports interface with ships and are responsible for cargo handling hence play a key role in shipping and cargo safety.

1) Ship Berthing and Unberthing Procedure (R_{41})
Water depth, shoreline length, number of berths, cranes, throughput, management capacity, service type and quality are important indicators of port capacity (Lam and Dai, 2011; Mansouri, 2010). These derive the standards for port management and operations. The major evaluation focus here is the safety level of ship berthing and unberthing procedure (Hu et al, 2007).

2) Cargo Loading and Unloading Procedure (R_{42})
The availability of appropriate cargo handling equipment, port’s competency in cargo operations and port’s responsiveness in any emergency form a necessary index to be included in the port operation performance assessment process (Mansouri, 2010).

4.5 Environmental factor (R_5)
Shipping operation is also determined by environmental factors which are the external risks affecting meteorological condition and seaworthiness to navigation. Such risks can be broadly classified into natural hazards and weather extremes.

1) Natural Hazards (R_{51})
This indicator includes earthquake, tsunami, volcano eruption and natural disasters alike concerning “low-frequency high-impact disruption scenarios” in the context of maritime risks. However, there is an increase in natural disasters over the past 30 years (EM-DAT, 2012) which means there could be higher
marine cargo exposure especially in seismically vulnerable regions.

2) Weather Extremes (R52)
The weather conditions influencing ship navigation include wind, fog, rain, snow, clouds and so on. As to sailing ship, the greatest impact on her navigation is wind which will in turn create waves (Toffoli et al., 2005). Ships at different routes or in different season would suffer from various impacts of waves (Bruce, 2008).

4.6 Geopolitical factor (R6)
Those risks involving the relationships among politics and geography, demography and economics are considered under the geopolitical factor.

1) Piracy (R61)
Piracy has been a threat to merchant shipping for long. Notably, the piracy crisis in the Gulf of Aden, off the coast of Somalia, and in the wider Indian Ocean, has worsened since 2008 (MSC, 2012). Analysis of piracy hijacking incidents suggests that state weakness encourages more sophisticated attacks (Hastings, 2009).

2) Political conflicts (R62)
Political risks such as war and terrorist attacks are also possible sources of shipping risks. Major terrorist hubs are located in the coastal regions, namely LTTE in Jaffna, Sri Lanka; Al Qaeda in Yemen, Somalia and Pakistan; the Abu Sayyaf Group in the Philippines, the Free Aceh Movement in Indonesia (MSC, 2012). The sea serves as a safe highway for those terrorist groups and acts as a catalyst for promoting terrorists’ activities if there are insufficient countermeasures.

5. Modelling by Rough Set Approach
This section presents a numerical analysis in evaluating marine cargo risk to demonstrate the computational process as described in above sections of the proposed approach. The analysis is based on an international shipping company located in Singapore. Thus it is an industry example demonstrating our model’s practicality.

5.1 Set up information table
U = {1, 2, 3, 4, 5, 6} represents the study objects, i.e. a set of marine cargo incidents, and each number stands for an incident that a shipping company had during shipping operation. Rij represents the 12 risk evaluation indicators as explained in section 4. Based on historical data from the incidents’ records kept by the company, a score of 1 to 5 is given to each indicator, with 5 being the highest risk exposure level. The scoring means that in one case, if certain situation is very tough, such as poor weather condition, then 5 is given to represent very high risk level. On the contrary, if an indicator is relatively reliable and safe, for instance competent cargo handling by the port, then 1 can be given to represent very low risk exposure in this aspect. In addition, the outcome on marine cargo is represented by D = {cargo incident outcome}. Y stands for cargo damage and/or loss, and N means no cargo damage/loss.

Uncertainty is inevitable no matter how experienced is the assessor and how much data is given to support the choice of a score. Moreover, the characteristic of the shipping industry is that the related conditions are changeable. For example, policies and economic environment are dynamic and we cannot use a certain standard to judge them (Jacobs and Hall, 2007; Panayides, 2003). Hence the record kept by shipping companies may be incomplete and have some flaws. This is especially true for shipping incidents since their occurrence is unanticipated and some data may be lost or unrecorded during the events. These features of the problem make the rough set approach an ideal methodology as it is capable in handling vague, inconsistent, uncertain and missing data by separating certain and doubtful knowledge extracted from exemplary cases (Pawlak, 1995; Grzymala-busse, 2003). Table 1 shows the initialized information in the numerical example for demonstration. The rough-set approach is flexible and can accommodate any number of objects and indicators as long as they are finite sets. Also, other values can be taken according to different cases. For instance, the incidents can be rated in a seven-point scale.
Table 1: Initialized information S'

<table>
<thead>
<tr>
<th></th>
<th>R_{11}</th>
<th>R_{12}</th>
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<th>R_{22}</th>
<th>R_{31}</th>
<th>R_{32}</th>
<th>R_{41}</th>
<th>R_{42}</th>
<th>R_{51}</th>
<th>R_{52}</th>
<th>R_{61}</th>
<th>R_{62}</th>
<th>D</th>
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<tr>
<td>1</td>
<td>4</td>
<td>*</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>*</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>Y</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
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<td>5</td>
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<td>2</td>
<td>Y</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>*</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>N</td>
<td></td>
</tr>
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<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>N</td>
</tr>
</tbody>
</table>

* denotes that data is unavailable and/or assessor is unable to give a score

5.2 Solution and analysis

5.2.1 Obtain similarity relation from information table

A denotes a subset of the attribute, i.e. risk evaluation indicators, a refers to a particular indicator within A. SIM(A) denotes binary similarity relation between objects that are indiscernible with regards to indicator’s value. The similarity relation can be defined as:

$$SIM(A) = \{(x, y) \in U \times U | \forall a \in A, a(x) = a(y), or a(x) = * or a(y) = * \}$$ (1)

Where (x, y) stands for pair of study objects. This means, two study objects (x, y) has binary similarity relation if the value of each attribute for object x, i.e. a(x), is the same as the value of the corresponding attribute for object y, i.e. a(y). For any value of attribute which is missing, i.e. a(x)=* or a(y)=*, a(x) and a(y) are considered the same since * can represent any number.

S_A(x) represents the maximal set of objects which are possibly indiscernible by A with x.

$$S_A(x) = \{y \in U | (x, y) \in SIM(A)\}$$ (2)

Referring to table 1, we compare the objects’ attributes. No object has the same attribute values as the other object. Hence, no objects are similar in this case. Then the similarity relation is given below.

S_A(1) = \{1\}
S_A(2) = \{2\}
S_A(3) = \{3\}
S_A(4) = \{4\}
S_A(5) = \{5\}
S_A(6) = \{6\}

5.2.2 Determine all reducts

A reduct is a minimal set of indicators from A that preserves the original classification defined by A. This can be determined by establishing Boolean Discernibility Matrix (Pawlak and Skowron, 2007) with \(\alpha_A(x, y)\) for any pair (x, y) of the objects. Place \(x \in U\) and \(y \in \{z \in U | d(z) \notin \delta_A(X)\}\) in table 2, where z is a particular object, d(z) is cargo incident outcome of object z showing in the last column of table 1, \(\delta_A(X)\) is the cargo incident outcome of object x. Let \(\alpha_A(x, y)\) be a set of indicators, which a \(\in A\) and (x, y) \(\notin SIM(A)\). This means, table 2 lists out those objects which are dissimilar in terms of cargo incident outcome. Let \(\Sigma \alpha_A(x, y)\) be a Boolean expression which is equal to 1, if \(\alpha_A(x, y) = \emptyset\). Otherwise, let \(\Sigma \alpha_A(x, y)\) be a disjunction of variables corresponding to attributes contained in \(\alpha_A(x, y)\). 

\(\Delta\) is a discernibility function for information table.

$$\Delta = \prod_{(x, y) \in U \times \{z \in U | d(z) \notin \delta_A(X)\}} \sum \alpha_A(x, y)$$ (3)
\( \Delta(x) \) is a discernibility function for Object \( x \) in information table.

\[
\Delta(x) = \prod_{y \in \{z \in U | \delta(z) \notin \delta_A(x)\}} \sum \alpha_A(x, y)
\]

(4)

<table>
<thead>
<tr>
<th>( x \backslash y )</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
</table>

5.2.3 Calculate the importance degree of each risk indicator

Then the importance degree of each indicator can be calculated by using the following equation:

\[
f(a) = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\lambda_{ij}}{\text{Card}(E_{ij})}
\]

(5)

In equation (5), \( \lambda_{ij} = 1 \) when \( a \in C_{ij} \), \( \lambda_{ij} = 0 \) when \( a \notin C_{ij} \).

\( C_{ij} \) represents a risk evaluation indicator appeared in Table 2.

\( \text{Card}(E_{ij}) \) means the total number of indicators in one entry of Table 2.

\( E_{ij} \) represents the element of Boolean Discernibility Matrix in Table 2.

Here is the calculation of R11’s importance degree as an example:

\[
f(R_{11}) = \frac{1}{5} + \frac{1}{8} + \frac{1}{8} + \frac{1}{10} + \frac{1}{9} + \frac{1}{10} = 0.87
\]

Thereafter, the importance degree can be normalized for easier comparison, which can be calculated by the following equation: \( \omega_{ij} = \sigma_{cd}(C_{ij}) / \sum_{i=1}^{n} \sigma_{cd}(C_{ij}) \), where \( \sum \omega_{ij} = 1 \). Table 3 shows the results. In this shipping company, the most significant risk evaluation indicators are R52 weather extremes, closely followed by R61 piracy and then R31 cargo attributes.

<table>
<thead>
<tr>
<th>( R_{ij} )</th>
<th>( f )</th>
<th>( \omega )</th>
</tr>
</thead>
<tbody>
<tr>
<td>R11</td>
<td>0.872</td>
<td>0.097</td>
</tr>
<tr>
<td>R12</td>
<td>0.336</td>
<td>0.037</td>
</tr>
<tr>
<td>R21</td>
<td>0.857</td>
<td>0.095</td>
</tr>
<tr>
<td>R22</td>
<td>0.804</td>
<td>0.089</td>
</tr>
<tr>
<td>R31</td>
<td>0.971</td>
<td>0.108</td>
</tr>
<tr>
<td>R32</td>
<td>0.436</td>
<td>0.048</td>
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<tr>
<td>R41</td>
<td>0.436</td>
<td>0.048</td>
</tr>
<tr>
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<tr>
<td>R51</td>
<td>0.857</td>
<td>0.095</td>
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<td>R52</td>
<td>1.057</td>
<td>0.117</td>
</tr>
<tr>
<td>R61</td>
<td>1.039</td>
<td>0.115</td>
</tr>
<tr>
<td>R62</td>
<td>0.882</td>
<td>0.098</td>
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</table>

5.2.4 Risk analysis

As illustrated above, the relative significance of risk factors can be revealed and quantified. Further insights can be obtained by knowing the relative risk exposure of each aspect. The equation “\( \Omega_{ij} = \omega_{ij} \times V_{ij} \)” can be used to calculate and evaluate the risk exposure of a shipping service. Like those values given
in table 1, $V_{ij}$ is given by assessor(s) from the shipping company. In other applications, the values can be obtained from a third party such as surveyor or from a combination of various creditable sources. Higher $Q_{ij}$ implies higher risk. Table 4 illustrates an example from which it can be seen that $R_{21}$ ship’s age having the highest $Q$ value of 0.476 represents the greatest risk, followed by $R_{61}$ piracy. Although $R_{32}$ weather extremes is the most significant risk evaluation indicator as shown in table 3, the risk score of 2 indicates that the shipping route’s weather is rather stable. Hence this $Q$ value is relatively low and would not be a high risk factor in this example.

Table 4: Risk analysis example

<table>
<thead>
<tr>
<th></th>
<th>$R_{11}$</th>
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<th>$R_{42}$</th>
<th>$R_{51}$</th>
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<td>$\omega$</td>
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<td>0.095</td>
<td>0.089</td>
<td>0.108</td>
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<td>0.048</td>
<td>0.050</td>
<td>0.095</td>
<td>0.117</td>
<td>0.115</td>
<td>0.098</td>
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<tr>
<td>$v$</td>
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<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
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</tr>
<tr>
<td>$Q$</td>
<td>0.291</td>
<td>0.149</td>
<td><strong>0.476</strong></td>
<td>0.357</td>
<td>0.324</td>
<td>0.194</td>
<td>0.097</td>
<td>0.050</td>
<td>0.190</td>
<td>0.235</td>
<td><strong>0.462</strong></td>
<td>0.294</td>
</tr>
</tbody>
</table>

This example can also be used for validating our rough set model. First, $\sum Q_{ij}$ indicating the overall risk level is calculated from samples with complete data, i.e. samples 2, 3 and 6 in table 1. The scores are 2.473, 3.643 and 2.455 respectively. Based on the cargo incident outcomes $Y$, $Y$ and $N$, the results reveal that 2.46 would be the score representing the risk threshold above which cargo incident is more likely to happen. Next, based on the example from table 4, $\sum Q_{ij}$ is 3.119 which means that cargo incident is likely to happen. According to the shipping company’s data, there was indeed cargo damage during this shipping service. We would like to highlight that it is not the purpose for the model to be a definitive guide to predict whether there will be a cargo incident or not, although higher $\sum Q_{ij}$ would generally reflect greater likelihood of cargo incident. Instead, the merit of the approach is to find out the influential risk factors in order to improve awareness and risk mitigation, which fulfills the major objective of this study.

6. Research and Practical Implications

The study has contributed to research and practice in various ways. First, the study has provided a novel method for analyzing marine cargo risks. In a broader sense, it is an original attempt to use the rough set approach for transportation risk problems. The novelty of this study is to address the concern of objective and precise weight of the factors in the framework of RST. This concern has not been tackled by the maritime safety and risk studies reviewed previously, and virtually majority of the studies applying RST. This is very crucial for any risk analysis since the reliability of research outcomes significantly depend on the attributes’ weight (Belton and Stewart, 2002). As illustrated by the example of a shipping company, we are able to calculate the significance of each risk factor based on the original data without assigning the weight subjectively. In fact, the main theme of RST is to measure the “ambiguity” inherent in the data and to reveal hidden patterns.

Second, the method is capable of handling missing data. Unlike statistical analysis, it is not necessary to discard samples with incomplete data. More samples can be retained when the rough set method is used which reduces the limitation of data problems. Quality solutions can still be obtained without the hassle to collect extra samples, if at all possible. The method’s advantage makes a valuable advancement to the risk management field.

Furthermore, the quantitative importance degree of the risk evaluation indicators reveals the major root causes of marine cargo incidents. Managerial implications can be drawn and appropriate actions can be taken accordingly. While all factors play a part contributing to safe shipping operations, due to cost
constraints in practice, shipping companies can pay particular attention to the most decisive factors and resources can be reallocated if necessary. For instance, $R_{32}$ weather extremes and $R_{61}$ piracy are found to be the most significant risk evaluation indicators in the company. These risks are generated from external sources so a possible way to reduce such risks is to transfer them by insurance policy. Another recommendation is to review the shipping routes and try to avoid high risk areas in terms of adverse weather and pirate active zones such as Somalia. The shipping company should also strengthen staff training in handling navigation and cargo operations during bad weather conditions and pirate attacks. Moreover, referring to a specific company and shipping service’s situation, risk exposure of each aspect can be quantified. High risk areas should be tackled first by utilizing appropriate risk mitigation measures. The study can strengthen the identification and monitoring of shipping risks. In addition to application by shipping companies in terms of operations safety, the rough set method offers insurance companies an alternative to assess safety status of the underwriting ships and cargoes and provides valid support for underwriting policy and decision making.

7. Conclusions and Future Research Directions

Maritime safety and risk management is an important topic affecting shipping companies, seafarers, cargo owners, insurance companies and regulatory authorities among others. It is necessary for stakeholders, particularly shipping companies and classification societies, to design, establish and apply effective risk assessment system. The merits of RST to handle incomplete and uncertain information, and its capability of minimizing subjective analysis have been exploited in this study. The paper established a systematic marine cargo risk exposure assessment, and also offered a guide for risk identification process in maritime-related business. By this, risk mitigation strategies can be formulated. In sum, a major contribution of this paper is demonstrating how to establish risk analysis with vague, dynamic, complex and incomplete data in maritime business.

Same as other studies, the paper contains research limitation. A rather low number of incidents are used for illustration. Future research can be devoted to examine more samples. However, we should note that the number of marine cargo incidents in a particular shipping company may not be very high in practice. Also, a low number of samples does not pose any problems in rough set algorithm. As a whole, the numerical example has clearly demonstrated the analysis and research outcomes, and has fulfilled the objectives of the research. Regarding more future research, the research process and model developed provide a lot of potential that study can be undertaken on other types of cargos, such as dangerous goods and refrigerated cargo, as well as other risk management topics.

Acknowledgements

The anonymous reviewer is acknowledged for the helpful suggestions. This research is partially funded by Singapore MOE AcRF project, NTU ref: RF20/10.

References


Munich Re 2012.