

A methodological framework for quantitative risk analysis in container shipping operations

Container
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risks

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Son Nguyen, Peggy Shu-Ling Chen and Yuquan Du

*Department of Maritime and Logistics Management, Australian Maritime College,
University of Tasmania, Launceston, Australia*

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Abstract

Purpose – Container shipping is a crucial component of the global supply chain that is affected by a large range of operational risks with high uncertainty, threatening the stability of service, manufacture, distribution and profitability of involved parties. However, quantitative risk analysis (QRA) of container shipping operational risk (CSOR) is being obstructed by the lack of a well-established theoretical structure to guide deeper research efforts. This paper proposes a methodological framework to strengthen the quality and reliability of CSOR analysis (CSORA).

Design/methodology/approach – Focusing on addressing uncertainties, the framework establishes a solid, overarching and updated basis for quantitative CSORA. The framework consists of clearly defined elements and processes, including knowledge establishing, information gathering, aggregating multiple sources of data (social/deliberative and mathematical/statistical), calculating risk and uncertainty level and presenting and interpreting quantified results. The framework is applied in a case study of three container shipping companies in Vietnam.

Findings – Various methodological contributions were rendered regarding CSOR characteristics, settings of analysis models, handling of uncertainties and result interpretation. The empirical study also generated valuable managerial implications regarding CSOR management policies.

Originality/value – This paper fills the gap of an updated framework for CSORA considering the recent advancements of container shipping operations and risk management. The framework can be used by both practitioners as a tool for CSORA and scholars as a test bench to facilitate the comparison and development of QRA models.

Keywords Risk analysis, Methodological framework, Uncertainty analysis, Container shipping supply chain, Operational risk

Paper type Research paper

1. Introduction

Container shipping operations are affected by a range of uncertain internal and external factors (e.g. weather, geopolitics, automation and digitalization), highlighting the significance of investigating container shipping operational risks (CSORs) (Tummala and Schoenherr, 2011; Chang *et al.*, 2015). However, risk management in container shipping has not been equipped with an adequate methodological framework. The groundworks of Manuj and Mentzer (2008) and Tummala and Schoenherr (2011) have not been updated with risk theoretical developments, especially regarding risk assessment's knowledge base and uncertainty. The absence of an adequate framework also leads to the incompatibility between concepts and models, obstructing the field's development (Goerlandt and Montewka, 2015). The missing link between risk foundation (e.g. risk ontological status) and the context of



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maritime logistics undermined efforts in risk identification, analysis result interpretation and post-analysis planning.

This paper proposes a versatile and generic quantitative risk analysis (QRA) framework for container shipping operations named CSOR analysis (CSORA), focusing on two prominent aspects. First, CSORA was built based on an updated risk concept, recognizing uncertainty as a central component of risk from the conceptual level. Second, an extension in analysis result interpretation was included, linking QRA to other risk management activities, such as iterative risk assessment and risk mitigation/prevention planning. An empirical study of the domestic container fleet in Vietnam with 15 most typical risk scenarios was conducted to demonstrate and validate the framework. The result's reliability is strengthened by proactively investigating uncertainty from a data-driven approach and the diversification of techniques.

The rest of the paper is organized as follows. The literature review in [Section 2](#) highlights the gaps of a new CSOR framework to tackle the existing issues. [Section 3](#) describes the framework's structure with a detailed explanation of its components, while the empirical study is presented in [Section 4](#). Finally, the analysis and interpretation of results are provided in [Section 5](#) before the conclusions are drawn in [Section 6](#).

2. Literature review

This section first reviews maritime logistics and container shipping literature to update the study with state-of-the-art CSOR management's development. It will then dive deep into container shipping to pinpoint two significant gaps that the CSORA framework aimed to fill, including (1) treating uncertainty as an organic component of risk and (2) improving the interpretation of CSORA results.

2.1 The developments of CSOR assessment and prioritization

The frameworks of [Manuj and Mentzer \(2008\)](#) and then [Tummala and Schoenherr \(2011\)](#) consist of fundamental elements for risk management activities in supply chains. In the physical flow, CSOR studies focus on the operation's stability and continuousness against a range of internal and external factors, such as infrastructure, supply and technology ([Øyvind et al., 2011](#)), social and political instabilities ([Calatayud et al., 2017](#)), critical weathers and natural disasters ([Lam and Lassa, 2016](#)), and safety accidents ([Alyami et al., 2014](#); [Goerlandt and Montewka, 2015](#)). In the information flow, solutions have been suggested to ensure data communication availability, punctuality and integrity between actors along the container supply chain ([Chang et al., 2015](#)).

Different methods and approaches had been applied for risk prioritization, focusing on two tasks of assessment aggregation (i.e. multiple assessments on a single object) and risk and uncertainty level calculation (i.e. multiple parameters of an individual risk) ([Bjørnsen and Aven, 2019](#)). CSOR models proposed different approaches to improve assessment aggregation, such as replacing arithmetic average ([Alyami et al., 2014](#)) with more superior algorithms such as evidential reasoning (ER) ([Alyami et al., 2019](#)), and deliberative techniques, such as Delphi ([Nguyen et al., 2019](#)). For parameter aggregation, the Bayesian network (BN) approach of [Yang et al. \(2008\)](#) has been widely applied thanks to its capability of reasoning a risk index (RI) from uncertain (i.e. probabilistic) inputs.

2.2 Uncertainty in CSOR analysis

Modern risk research recognizes uncertainty as a core component of the risk concept ([Aven, 2012](#)). In container shipping, external factors, such as technology adoption, geopolitical events and regulation enforcement, and the COVID-19 pandemic magnified

the uncertainties in CSOR (Haralambides, 2019). Those factors account for the low availability of data (e.g. observations, event logs and leading indicators) and their deteriorating explaining power's (Lechler et al., 2019). However, uncertainty in CSORA has not been handled adequately. The reliability of CSOR analyses depends on the methodological handling of *evidential uncertainty* – U_E , rooted in the base of evidence used for risk assessment, and *outcome uncertainty* – U_O , sourced from the unrevealed nature of future disruptive events (DEs) (Goerlandt and Montewka, 2015). Risk analyses in the field are still primarily relied on the definition of risk as the product of likelihood and consequence (Chang et al., 2015; Vilko et al., 2019), ignoring insights into the knowledge base of risk assessments. Risk parameters are often derived directly from the risk definition, which will prevent any further insights into the level of uncertainty (Renn et al., 2011; Aven, 2012). Even though some uncertainty handling methods were proposed (e.g. uncertainty modelling (Alyami et al., 2019) or dedicated uncertainty module (Nguyen et al., 2021)), they were not guided by any foundational framework. Therefore, the foundational elements (e.g. risk concept and taxonomy) are not agreed or even not communicated, affecting not only the relevance of the risk analysis in informing decision-making, risk mitigation and prevention but also the communication and applicability of CSORA models (Goerlandt and Montewka, 2015).

2.3 Usefulness and interpretation of analysis results

The usefulness of insights and suggestions drawn from the analysis validates the QRA model (Goerlandt et al., 2017). Vilko et al. (2019) suggested that higher collaboration between actors is needed to be aware of and successfully control their own set of risks. The usefulness of a CSORA should be further than merely prioritizing risks. Nevertheless, it was not communicated, analysed or even involved in the risk analysis processes and the result interpretation of many CSOR studies. There are calls for the field to be more connected to more practical issues, such as technology integration and data-driven decision-making (Choi, 2021). A CSOR framework should be designed to enhance the interpretation of risk analysis results.

3. Structuring CSORA – a risk analysis methodological framework

Risk analysis aims to investigate and interpret the upcoming situation of risk, breaking down the concept of risk into more measurable components and capturing their predictive statuses. This section presents the methodological framework, namely CSORA, with five steps to build up a five-level structure for CSORA (Figure 1). Module 1 – Section 3.1 presents the philosophical and epistemic basis of the framework, while Module 2 – Section 3.2 introduces general guidance of how risk data and assessments are collected, processed and analysed.

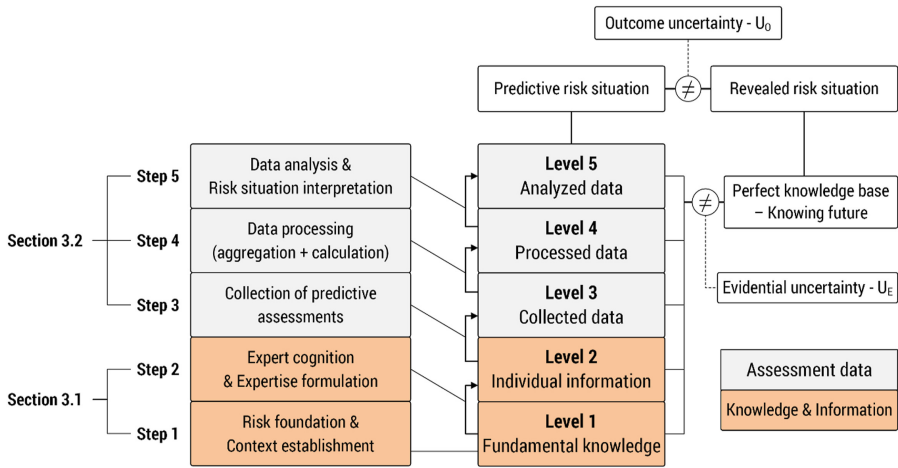
3.1 Knowledge and information establishment

3.1.1 Risk foundation and context establishment. 3.1.1.1 Foundational risk understandings.

Being foundational does not mean that these elements are isolated from the context of usage. CSORA includes three foundational elements: risk concept, uncertainties and primary parameters.

- (1) Risk concept: container shipping consists of cyber-physical systems operate on three flows of information, physical movements and payments. Therefore, CSORs are multidisciplinary and require a holistic concept of risk that can be applied for operational risks in multiple fields. CSORs are characterized by the immediate development and time-varying consequences after the DEs. These factors favour the risk concept of $R = (DE, C, U)$, where a risk (R) comprises a DE, its consequence (C)

Figure 1.
The CSORA
methodological
framework for
container shipping
operational risk
analysis



and the attached uncertainties (U). This is a development in comparison with the [Manuj and Mentzer \(2008\)](#)'s risk concept of consequence and probability. Uncertainty is recognized as a component of risk instead of probability, which is only an artificial, mathematical concept that incompletely presents uncertainty ([Aven, 2012](#)).

- (2) Uncertainties: outcome uncertainty – U_O sources from the fact that the future risk situation is not determinate at the time of analysis. Evidential uncertainty – U_E , on the other hand, roots in the imperfection of the base of evidence used in risk analysis. The updated taxonomy used in CSORA differentiates between U_O and U_E .
- (3) Primary risk parameters: branching to multiple specific parameters allows more deliberative, data-supported reasoning/arguments. However, it also narrows down the scope and limits the potential of direct result comparisons/reuses. CSORA tackles this problem by dividing the parameter set into *primary risk parameters* – the common interface and *secondary risk parameters* – the customizable interface. Primary risk parameters include likelihood of occurrence (L) and severity of consequence (S), which are the properties of risk components DE and C.

3.1.1.2 Contextual knowledge – container shipping operations. The container shipping context in CSORA is to avoid unnecessary context ambiguity ([Renn et al., 2011](#)). Four contextual knowledge elements include container shipping operations, CSOR definition and identification, and secondary risk parameters.

- (1) Container shipping operations: there are many container shipping operations (e.g. hauling, stuffing, loading/unloading, customs clearance and sea/road/rail transport). Depending on the boundaries of the CSORA operations in analysis and the corresponding risk bearers/takers, the included operations and specifications of analysis will be clarified.
- (2) CSOR definition and identification: with the established elements, CSORs can be identified by employing appropriate methods (e.g. qualitative analyses and causal analyses). In CSORA, risk identification is guided by the risk concept, resulting in qualitative descriptions of groups of potential scenarios. This setting formalizes the generalization–specification flexibility in finalizing the final CSOR list.

- (3) Secondary risk parameters: the secondary risk parameters consist of aspects through which L and S can be expressed. They reduce the ambiguity in providing assessments of the expert panel and connect the task of assessing risk primary parameters with the available databases. More parameters allow a more detailed risk description but could amplify the number of assessments needed and defeat the advantage of providing generalized and experience-driven risk assessments (Rae and Alexander, 2017). The empirical study in this paper used financial, reputational and operational to describe the severity of consequences, denoted as F , I , O respectively.

3.1.2 *Expert cognition and expertise formulation.* This step connects the foundation in Level 1 with the experts' experience background and cognitive ability for risk assessment. The second level of the structure – *individual information* consists of *risk perspective*, *private information* and *domain knowledge*.

- (1) Risk perspective: the scales describing the magnitudes of risk parameters (e.g. “low” and “high”) can cause biases in assessment aggregation. Different stakeholders have dissimilar risk perceptions, attitudes, tolerance thresholds that the assessment scales should reflect. This element provides a universal grading platform for the experts to work on.

Besides the risk perspective, the expertise behind risk assessments is crucial toward the reliability and validity of the CSORA (Goerlandt *et al.*, 2017). Expertise is considered by Rae and Alexander (2017) as constituted in risk analysis through two mechanisms of private information (information that only experts possess or can access) and domain knowledge (experts' understanding of the specific operations and mechanism of the subjected supply chain).

Denoting K as the knowledge and information basis derived after Step 2 (Figure 1), we have the description of CSORs as $R \sim (L, S|K) \Leftrightarrow R \sim (L, F, I, O|K)$, where L is the likelihood of occurrence, $S \sim (F, I, O)$ is the severity of consequence.

3.2 Data collection, processing and analysis

3.2.1 *Data collection.* For each identified CSOR, experts will provide their predictive assessments regarding each risk parameter of the CSOR scenarios they speculated (L , F , I , and O). With the proposed risk parameter set, the dataset in Level 3 will be a matrix of total $4 \times m \times n$ data entries (m : number of CSORs, n : number of experts). The extracted data in this level can be described as a $n \times m$ matrix D_E .

$$D_E = \begin{bmatrix} (L, F, I, O)_{11} & \cdots & (L, F, I, O)_{1m} \\ \vdots & \ddots & \vdots \\ (L, F, I, O)_{n1} & \cdots & (L, F, I, O)_{nm} \end{bmatrix}$$

3.2.2 *Data processing.* There are two distinct processes conducted on the extracted data (Bjørnsen and Aven, 2019). The first process – *assessment aggregation* aggregates multiple assessments regarding the same parameter of each CSOR. The second process – *risk and uncertainty quantification* combine multiple parameters to gain information about the overall risk magnitude.

- (1) Assessment aggregation: risk assessments provided by different experts in Level 3 will be aggregated in Step 4. The aggregated data in this level can be described as a vector $D_A = Aggregation(D_E) = [(L, F, I, O)_1, \dots, (L, F, I, O)_m]$. The aggregation methods here can be either deliberative/social or statistical/mathematical.

- (2) Risk and uncertainty level quantification: these quantities do not have an agreed formula of quantification in CSOR literature. The calculated risk level in this step can be described as a vector $D_C = [(L, S, U)_1, \dots, (L, S, U)_m] \Leftrightarrow D_C = [R_1, \dots, R_m]$. The set of (F, I, O) in D_A is used to calculate S , while the calculation of uncertainty indicators results in U (e.g. standard deviation (SD) of assessments). An example of such a calculation system will be described in [Section 4](#).

3.2.3 Data analysis and risk situation interpretation. There are two primary outputs generated in Step 5. *Risk prioritization* simply provides an ordinal view obtained from risk ranking, while *result mapping* depicts results' relative magnitudes and continuity in different coordinate systems.

- (1) Risk prioritization: in addition to risk magnitude prioritization, CSORA allows more in-depth insights into the uncertainty of risk. The availability of uncertainty quantification helps iteratively improve the analysis. To the decision-maker, it reflects the possibilities of under- and over-estimation in risk analysis results.
- (2) Risk mapping: this process uses methods of visualization to present the overall risk quantification results to support decision-making. Two- and three-dimensional diagrams can be used to display levels of risk parameters and uncertainties. This framework suggests and encourages creative presentations that can provide more insights into the situation of risk.

4. An empirical study of domestic shipping companies in Vietnam

4.1 Context establishment

Vietnam's logistics system is in fast-paced development to keep up with the manufacturing industry's increasing demands. Practitioners have mentioned Vietnam as the potential next manufacturing hub of the region after China, thanks to its low manufacturing costs, skilled labour force and geopolitical and economic stability. However, the country's logistics system was reported as being unprepared to catch the opportunity. Multiple factors are now favouring a trend of shifting manufacturing activities from China to adjacent regions, where Vietnam stands out as a promising alternative. Investigating CSORs to improve the quality of the logistics services in Vietnam is, therefore, worthwhile as a research objective.

In the five largest container shipping companies in Vietnam, three (60%) agreed to participate in this study. Together, these companies manage approximately 40% of the twenty-foot equivalent unit (TEU) capacity of Vietnam's container fleet, operating multiple lines between Haiphong, Danang and Ho Chi Minh City. Company A is operating approximately 3,000 TEU total capacity of four feeder container ships for primarily domestic shipping services. Inland-waterway consolidation services of Company A focus on agriculture-related cargoes (e.g. agriculture products and agrichemicals), supported by an infrastructure of more than 40 barges and a large semi-trailer fleet. Company B is operating a multi-purpose port in Haiphong and a fleet of five feeder-size container ships with a gross capacity of almost 5,000 TEU. Company B provides domestic and short-sea shipping services to ports in the Southeast Asia region. Shipping and consolidation services for customers in the northern industrial zones are an important segment of the company. Company C is operating a fleet of six container ships with a total capacity of almost 5,000 TEU. Domestic container shipping and a short-sea route to Singapore are its main businesses. There is also a plan of Company C to expand to larger ship size (4,000–8,000 TEU). However, the project is currently on hold due to unstable economic and market situations.

The empirical study in this paper deployed two multiple methodological pathways, covering 15 common CSOR scenarios from shipping companies' perspective ([Manuj and](#)

Mentzer, 2008; Chang *et al.*, 2015) (Table 1). The database contains expert assessments regarding four parameters (L , F , I , O) for each CSOR in their companies.

4.2 Expert cognition and expertise formulation

Multiple experts with heterogeneous background experience are recommended by the CSORA framework. Potential experts were identified satisfying both criteria: (1) more than ten years of container shipping operation experience in which at least five years in the current company and (2) currently holding a managing position with at least two years of experience. Out of 36 experts identified from three companies, 19 agreed to participate, seven from Company A (participation rate 63.6%), six from each of Companies B (participation rate 50%) and C (participation rate 46.1%) with an average experience of 13.7 years. Various backgrounds were included in the panels with cases of experts in multiple fields, including operation and trading (31.6%), shipping financing and accounting (31.6%), maritime transport with onboard experience (36.8%), sale and customer relation (10.5%), information systems upgrade and maintenance (21.0%). An expert panel was established in each company for Delphi to be implemented as the deliberative communication platform. A system of definitions for different states of each parameter has also been agreed on before Step 3 of collecting assessments.

4.3 Assessment collection

Inputs are in the form of probability distributions corresponding to low, medium and high. Multiple rounds of surveys were administrated and facilitated through emails from November 2018 to March 2019.

4.4 Data processing

Two different methodological pathways were applied in this study. Pathway 1 first uses arithmetic average and ER for the aggregation of raw assessments. The BN is then employed to calculate the level of risk (RI) based on aggregated assessments of risk parameters (Yang *et al.*, 2008; Alyami *et al.*, 2014). Pathway 2 uses the average risk indexing method to calculate the risk level for each expert before aggregating those results (Chang *et al.*, 2015; Vilko *et al.*, 2019).

4.4.1 Pathway 1 – segregated assessments. 4.4.1.1 Assessment's aggregation. There are two common assessment aggregation methods. Arithmetic average is widely applied in CSOR studies for its simplicity. On the other hand, ER is developed from the Dempster–Shafer theory to handle incomplete probability (Yang and Xu, 2002). It treats probabilities from multiple sources as evidence with an accumulative reasoning effect, meaning that similar assessments will be stacked in the aggregated result.

4.4.1.2 Risk level calculation. The aggregated assessments are inputted into the BN built from the structure of risk parameters. The quantitative core of BN is powered by the conditional probability tables (CPTs). For the methodological details of BN, readers are referred to the studies of Yang *et al.* (2008) and Alyami *et al.* (2014). L and S describe two different components of the risk concept and therefore are considered equally important (w_L, w_S) = (0.5, 0.5). Using a simple five-point Likert scale for importance assessments, the weights of financial (w_F), reputational (w_I) and operational (w_O) impacts were derived ($w_F = 0.4428$; $w_I = 0.2836$; $w_O = 0.2736$).

Two interpolation methods were applied to build CPTs. The first method – *multi-state CPT* injects the importance of parameters into the CPT. The probability of a node at a state can be calculated by adding the weight of all parent nodes at the same state. The second method – *single-state CPT* uses the risk classification feature of risk matrices to simulate

Flow	Code	Description
Information	IT1	Unexpected delays of documents and administrative procedures for the shipment, container or ship. While related stakeholders and authorities are adopting digitalization in Vietnam, the progress is still slow with potential errors and unrealizations of additional duties. Potentially complicated situations could also be caused by sudden changes in policies and regulations (e.g. COVID-related requirements for cargoes, seafarers and shipper representatives)
	IT2	Cybersecurity-related DEs such as cyberattacks, cybercrimes and cyberwarfare. Vietnamese container shipping companies are small and thus usually allocating a minimum investment for cybersecurity activities, such as education, system security maintenance and security solution outsourcing
	IT3	Non-standardization and incompatibility of ICT systems. Vietnamese shipping companies use different channels, protocols and data formats for intercorporate communication. Their ICT capability is also limited by the underdeveloped onshore and offshore infrastructures (e.g. computing devices)
	IT4	Wrong cargo information DEs such as cargo misdeclaration, outdated shipment information. Cargo misdeclaration is a major risk faced by shipping companies. In many cases, shippers intentionally declared incorrect cargo content for financial gains, avoid additional fees and even customs procedures
	IT5	Unsuitable human operations and human errors in ICT systems. Most information operations still require human initialization, monitoring and intervention. Erroneous operations could cause system outages, information leakage and even unrecoverable data losses
Physical	PS1	Delays due to unavailability or congestion of port infrastructures such as terminal, road or berth. Despite the development and expansion of container terminals in the region, port congestions still happen. The situation also applies to Vietnamese ports, which struggle to keep up with the increasing migration of logistics and manufacturing activities from China
	PS2	Detainment of container vessel or its cargoes by authorities. This event could be caused by lacking updated documents related to the ship, the on-board crew or the cargoes (e.g. detected drug trafficking, smuggling and outdated seafarer documents)
	PS3	Maritime accidents of container vessels (not include cargo-related accidents). Many cases of ships collisions with ships, cranes, containers overboard and even shipwrecks that obstruct traffic in/out terminals have been recorded over the years in Vietnam
	PS4	Cargo-related DEs on-board container vessels such as fires, explosions and leakages. Although these incidents are relatively rare with Vietnamese shipping companies, the consequences are significant with recorded injuries and potentially catastrophic losses if the events could not be detected and controlled timely
	PS5	Shipments, containers or vehicles being stolen or tampered with in transport and logistics processes. In Vietnam, incidents have happened in which perpetrators stole cargoes inside the container or even the whole container by exploiting inadequate security measures or colluding with insiders and corrupted officials
Payment	PM1	Delays of payment (both intentional and unintentional) from logistics partners. A balance between certainty in payment and customer relations should be kept. The current business environment and practices of many partners in Vietnam, especially shippers, require close monitoring of payment progresses
	PM2	Unrealized contract or agreement with logistics partners. This type of event does not frequently happen. However, it is still a possibility with new partners and customers. There are various cases in which Vietnamese shipping companies and freight forwarders found themselves in legal disputes or unexpected liabilities because of overlooking contracts and regulations
	PM3	Unexpected rise of operational costs. Bunker is a major category of operational cost. Multiple factors contribute to fuel price fluctuation, including governmental/intergovernmental policies, the global economy and geopolitical situations. In addition, the Vietnamese container fleet is ageing, and shipping companies are struggling to prepare for progressively stricter environmental regulations
	PM4	Unexpected reduction in the volume of transport or cancellation by customers. Fierce competition in the freight market and the expansion of larger competitors encourage riskier business decisions. In addition, shippers are sometimes affected by supply chain disruptions (e.g. COVID-19), affecting the availability of transport demand
	PM5	Abandonment of containers or shipments at the port of destination. There are many cases in which the consignors or consignees are unable or intentionally abandon the transported containers (e.g. bankruptcy, legal difficulties and financial unsoundness)

Table 1.
List of CSORs in the empirical study

different risk-taking attitudes (risk-seeking and risk-averse). The matrices are established to follow Cox (2008)'s rules of weak consistency, betweenness and consistent classification. For this study, following these rules results in one set of consequence classification and two risk classification sets for risk-averse and risk-seeking attitudes (Figure 2).

Utility values – the RI of risks was calculated to present risk levels based on the results of the BN, which is $p(R_j), j = 1 \rightarrow 3 \sim j \in \{Low, Medium, High\}$ (Equation 1). The RI will be computed using the logarithmic scale of attention factor V at each state: $V_1 = 10^0; V_2 = 10^1; V_3 = 10^2$ (Yang et al., 2008; Alyami et al., 2014).

$$RI = \sum_{j=1}^3 p(R_j) V_j \tag{1}$$

4.4.1.3 Uncertainty level calculation. U_O of each risk was measured in this pathway by calculating the average discrepancy Δ_A among n experts. This index was calculated using the non-aggregated assessments, with all pairs of experts, denoted as u and v (Equation 2) for all four parameters $i = 1 \rightarrow 4 \sim i \in \{L, F, I, O\}$. U_E of each risk was measured by the average assessment polarization remainder Δ_P of the aggregated assessments, indicating the inability of experts in providing decisive assessments. Denoting \hat{d}_{ij} as the aggregated assessment regarding parameter i at state j , we have the formula for Δ_P in Equation (3).

$$\Delta_A = \frac{\sum_{i=1}^4 \sum_{u=1}^{n-1} \sum_{v=u+1}^n w_i |d_{iu} - d_{iv}|}{\frac{n(n-1)}{2}} \tag{2}$$

$$\Delta_P = \frac{400}{3} - \left(\sum_{i=1}^4 w_i \sum_{j=1}^3 \left| \hat{d}_{ij} - \frac{100}{3} \right| \right) \tag{3}$$

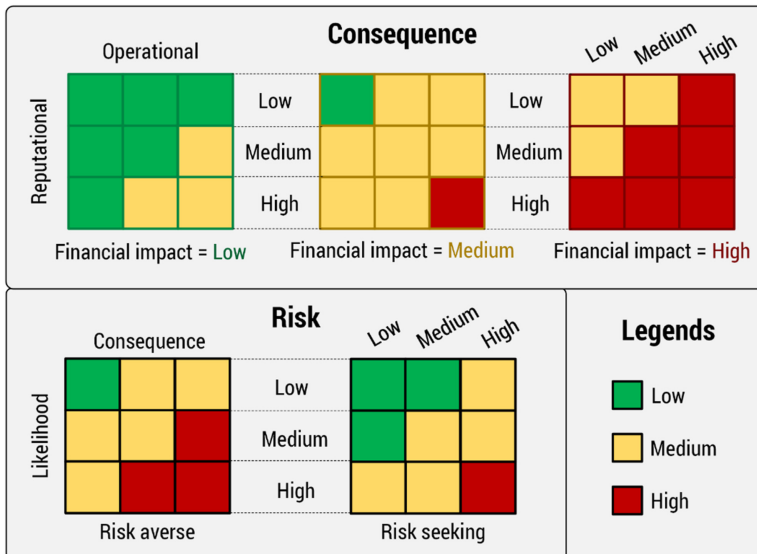


Figure 2. Risk classification using risk matrices

4.4.2 Pathway 2 – synergetic assessments. To simulate data for this pathway, in which only a single value is received (e.g. linguistic assessment and Likert scale), a scalar value of each probability distribution (d) was calculated, with the factor of 1 for the probabilities of low, 2 for medium and 3 for high. Based on the nature of the parameters, S was calculated as the weighted sum of F, I, and O; and the risk level (RI) were calculated by multiplying S with L. Arithmetic means were used to aggregate these assessments.

Since the probabilistic assessments are all transformed into scalars, U_O and U_E following the explanation in Section 3.4.1.3 cannot be expressed separately. Instead, the uncertainty in this pathway was usually only reported by calculating standard deviation in previous CSOR studies (Chang *et al.*, 2015; Vilko *et al.*, 2019). This study added the range of min–max to consider the dispersion and outliers of scenarios.

5. Results and discussions

Section 5.1 shows the prioritized risk lists and compares the results of two aggregation methods in Pathway 1. Section 5.2 discusses prioritization results using risk-seeking and risk-averse attitudes and compares single-state to multiple-state CPT interpolation method. Section 5.3 compares the results of Pathway 1 and Pathway 2, while Section 5.4 uses risk maps to gain more risk situation insights.

5.1 Effects of aggregation methods and representativeness of CSOR prioritization

The risk prioritization result of Companies A, B, C and overall (T) in Pathway 1 with two aggregation methods (A – Arithmetic average and E – ER) is in Figure 3. The results indicate only marginal differences between aggregation methods, indicating the results' robustness over all four sets of data (A, B, C and T). Especially, only a 1-rank change at the bottom of the overall result (TA and TE) was detected. This consistency can be explained through the indecisiveness of the probability distributions. The accumulative effect of ER in combining assessments is only significant with similar, decisive assessments (low Δ_A and Δ_P), which hardly exists in most CSOR situation. This finding suggests the application of ER should focus on its capability of handling incomplete risk assessments (i.e. unassigned degree of belief).

Figure 3 also indicates a relatively large difference in Company A's results from companies B, C and overall. The risks of maritime accidents (PS3) and unstandardized information technology (IT) systems (IT3) are more prioritized by Company A, while the risk of container abandonment (PM5) is less concerned. PS3 is affected by the insurance package

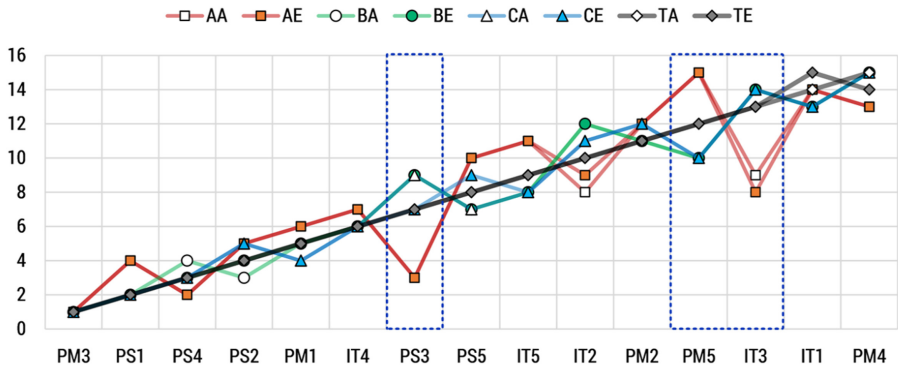


Figure 3. Prioritization results by companies and aggregation methods

and the route conditions, capability and experience of the on-board crew, availability of contingency plan (e.g. repairing and the flexibility of operation). Since Company A's fleet is called at terminals and ports operated by its parent company, maritime accidents are frequently followed by other DEs, including traffic disruption, obstructed navigation, damaged equipment and inoperability of berths or terminals. Regarding IT3, the company has to maintain a versatile IT system that is compatible with modern solutions of its parent company, yet able to communicate with agricultural shippers and logistics partners. This characteristic and the domestic-focused services, on the other hand, lower the risk of container abandonment.

This result suggests that each company's risk situation is heavily affected by different unique factors. Multi-organizational CSOR prioritization, therefore, is rather an investigation of these organizations' common concerns over typical CSORs, which is more helpful for multilateral policy and regulation development than improving individual companies' operations.

5.2 Effects of risk attitudes and methods of CPT interpolation on CSOR prioritization

The prioritization results and RI values indicate a "middle zone of uncertainty" where ranks are highly uncertain across different approaches (Figure 4). On the other hand, the upper and lower parts of the list are relatively consistent. This result proves that different attitudes toward risk cause the global changes of risk levels (e.g. risk-averse attitude receives higher RIs) and the result of risk prioritization. Using an attitude-integrated perspective, especially risk-averse, might lead to over- or under-estimating risk levels, especially risks that have low L and high S.

Changes are observed from rank third to tenth, with the notable case of PS4 – Fire and explosion of dangerous goods that changed from fourth to tenth when changing to risk-averse attitude (Figure 4). Since PS4 is a risk with extremely low probability and high consequence, the marginal probabilities of medium scenarios (e.g. high L, medium S) are less rewarded by changing to risk-averse attitude. Meanwhile, disproportionate increases of RI are observed across all CSORs, where higher risks tend to gain more RI than lower risks. The prioritization results of the multi-state CPT approach are relatively closer to that of risk-seeking than risk-averse attitude.

These observations have several implications. *First*, the single-state approach in BN CPT building, or using risk matrices in classifying risks in general, while seeming intuitive and

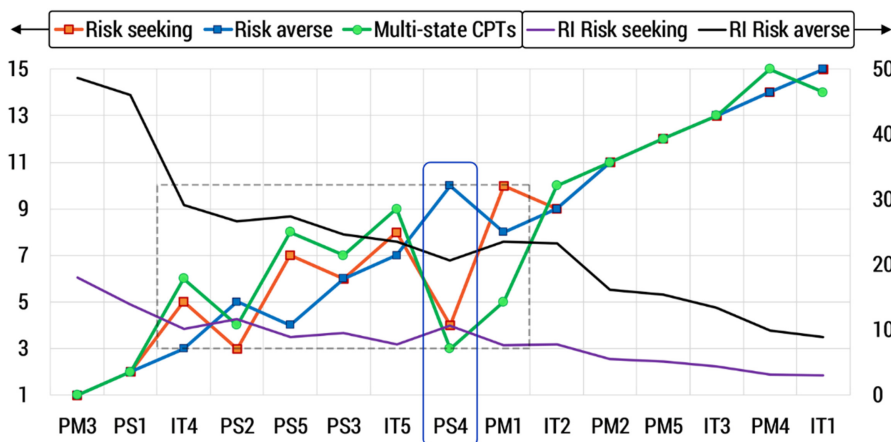


Figure 4. Prioritization results and RI values of different risk attitudes

simple, should not be used as a standalone method. *Second*, using an attitude-integrated perspective, especially risk-averse, might lead to over- or under-estimating risk levels. Therefore, it is recommended to investigate uncertainty, especially for risks that have low L and high S. *Third*, the characteristics of each CSOR should also be considered for multi-dimensional assessments instead of only magnitude prioritization, especially with risks in the “middle zone of uncertainty”.

5.3 Methodological uncertainty in CSOR prioritization

The prioritization results of CPT building methods in Pathways 1 and Pathway 2 are illustrated in Figure 5. The rank differences across risk prioritization approaches of CSORs in “middle zone of uncertainty” zone are significantly higher than others. Correspondingly, the normalized RI data of all approaches indicate a substantially dense middle range of RI value, while a relatively sparse one can be observed with other risks. Among risk prioritization models, average indexing – Pathway 2 seems to deliver less distinguishable results. The single-state CPT BN model provides the largest range of value, but as discussed in Section 4.2, it might exaggerate or understate risk situations through the unbalanced risk matrices of risk attitudes. The multiple-state CPT BN model is relatively more balanced, with more steady gaps between risks.

The prioritization results from Pathways 1 and 2 reflect PM3 and PS1 as the highest-ranked CSORs. High PM3 level implies the vulnerability of Vietnamese container shipping companies, or shipping companies at this size, in general, to the fluctuation of fuel costs. The competitive and unstable environment of the market and the limited forecasting capability obstruct mitigation/prevention efforts, such as bunker surcharges, fuel hedging and slow steaming. Vietnam’s developing logistics infrastructures have also experienced serious congestions and delays in its ports and connected systems observed in 2019–2021 when the demand increased, thanks to global supply chain restructurings. This result suggests the limited logistics capability and infrastructure constraints are hindering Vietnam’s possibility of becoming a manufacturing alternative to China.

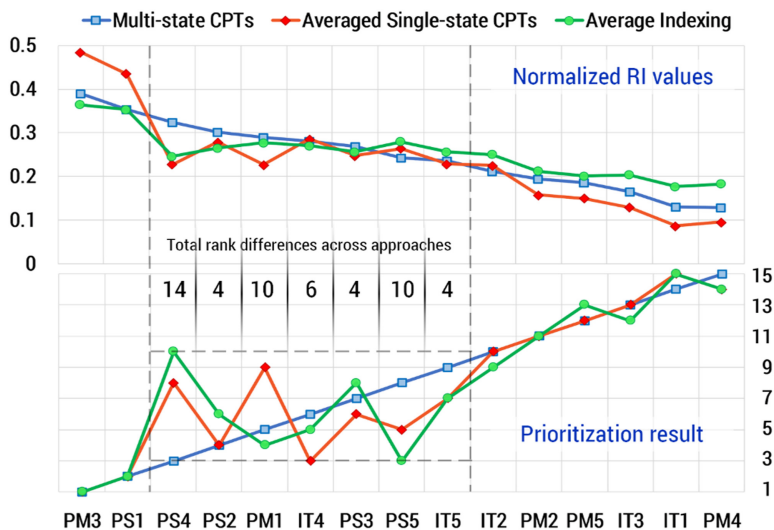


Figure 5. Prioritization results and RI values of methodological pathways

5.4 Uncertainty reporting and risk mapping for CSOR situation interpretation

Risk mapping can be an effective tool to provide a more comprehensive overview of the risk situation. Figure 6(a) shows the map of CSORs represented by circle markers. A risk with a bigger circle has a higher overall uncertainty. CSORs can be distinguished based on their parameters' magnitudes. Risks along the diagonal of the map in Figure 6(a) are mostly moderate risks.

Several observations can be made through these risk maps. *First*, adjacent CSORs can be distinguished based on their parameters' magnitudes. Risks along the diagonal of the map in Figure 6(a) are mostly moderate risks with high methodological uncertainty. Information provided by the risk map is useful in putting forward mitigation/prevention suggestions. For example, PS4 has the lowest L but high S and, therefore, should be mitigated through insurance, prevented by maintaining safety protocol and consequence-controlled through emergency response. *Second*, methodological uncertainty is different from uncertainties observed on the inputs. Some risks exhibit low/medium uncertainty but show relatively high methodological uncertainty (e.g. PS2, PS4 and PM1) and vice versa (e.g. PS1, IT3, IT4 and PM5). *Third*, the three flows have different risk characteristics. Physical risks are higher in terms of S and average RI (3.44); information risks have medium L and S with lower overall RI (2.84); while payment risks are scattered across the map with medium average RI (3.04). *Fourth*, Figure 6 (b and c) provide a more in-depth view into the uncertainty of CSORs. The potential of varying scenarios can be traced back to the risk's primary parameters through these maps. For example, IT3 and PS1 have high uncertainty regarding their likelihood, suggesting further analyses into their causing factors. On the other hand, PM5 and IT4 have higher uncertainty in their consequence; thus, further analyses are needed to investigate their mechanism of causing damages.

Although calculated in two different methodological pathways, the indicators of difference between experts' assessments of Pathways 1 (Δ_A) and 2 (SD) show the robustness of analysis results (Figure 7(a)). Meanwhile, Δ_P reflects a different pattern, suggesting the distinction of the information it conveys. This result also suggests the usefulness of risk assessments following Pathway 1 compared to Pathway 2.

There are several remarks regarding the uncertainty of CSORs in the empirical study. *First*, there are risks with relatively low RI but high uncertainty, including IT3, PM2 or PM5. For example, IT3 would be temporarily ignored and put into a watchlist based on the traditional CSOR analyses; but knowing its high Δ_A and Δ_P , uncertainty lowering strategies can be applied. Results of IT3 in Figure 6 (b and c) favour a fault tree analysis to address a large range of L. *Second*, high risks, such as PM3 and PS1, have low Δ_A but high Δ_P . This indicates the difficulty in specifying a decisive risk scenario across all experts, thus

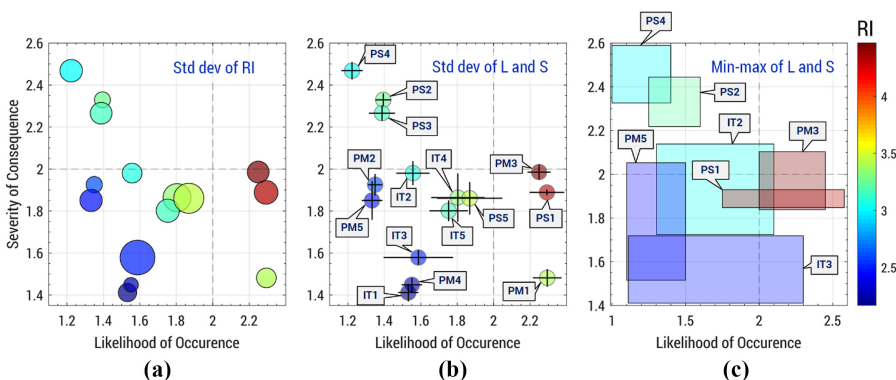


Figure 6. Risk mapping results of Pathway 2 for primary parameters

suggesting a supplementation of data (e.g. consultancy, forecasting data and expertise). Uncertainty lowering strategies for risks, such as IT4 and PS5, should be developed for both U_O and U_E . For example, reliably assessing PS5 might require expertise and knowledge of trucking managers, port operators and container suppliers while concurrently branching it into different transport chain legs for specific analyses and mitigation/prevention. *Third*, while posing a relatively lower risk, information risks are suffering from higher uncertainty than risks in other flows. All indicators of Pathways 1 and 2 agree that information risks are highly uncertain. This result aligns with the maritime shipping and the insurance industry's recent attention toward cybersecurity that worth more investigation.

Apart from the primary parameters, the framework uses the second level of parameters to capture aspects of consequence, including financial, reputational and operational. With CSORs that have high consequence, such as PS2, PS3, PS4, PM3 and IT2, or high uncertainty attached to consequence, such as IT4 and PM5, further analyses to specific impacts should be facilitated. Figure 8 presents three-dimensional mapping results from Pathway 2 of consequences. Markers' colours present the quantified levels, with their sizes indicate the standard deviation. This presentation can be used to put forward contingency and consequence controlling plans. For example, IT2 could cause high operational impacts. The risk-counter efforts, therefore, should be to ensure the system operability in DEs, e.g. cyberattack. IT2 also has high Δ_P , low L and high S. Therefore, cybersecurity insurance, establishing backup IT infrastructures and emergency operation plans, and cybersecurity outsourcing are recommended. It is noteworthy that, many cybersecurity insurance packages currently do not cover items such as reputational losses, losses of important intellectual properties or trading information, reduction of the avenue and business disruptions.

While PM3 does not heavily affect the carriers' reputation, it can cause significant damages financially and operationally, especially to smaller fleets. PM3 is also a risk with high Δ_P , high L and medium S. Negotiating bunker surcharges with major shippers; improving fuel price forecasting capability and fuel hedging are recommended actions. PS3 and PS4 are at the furthest corner of the map, posing high consequences. While insurance can cover them, the significant residual risk is still concerned by small shipping companies (e.g. shrinking fleet, changes of schedule, supply chain disruption and potential injuries or casualties). Addressing them requires improving operating skills and maintaining safety standards (e.g. safety protocols and contingency plans), the infrastructure readiness (e.g. safety equipment) and better collaboration with logistics partners to reduce cargo misdeclaration. This result confirms the previous finding that smaller carriers are facing higher operational risk compared to bigger shipping companies.

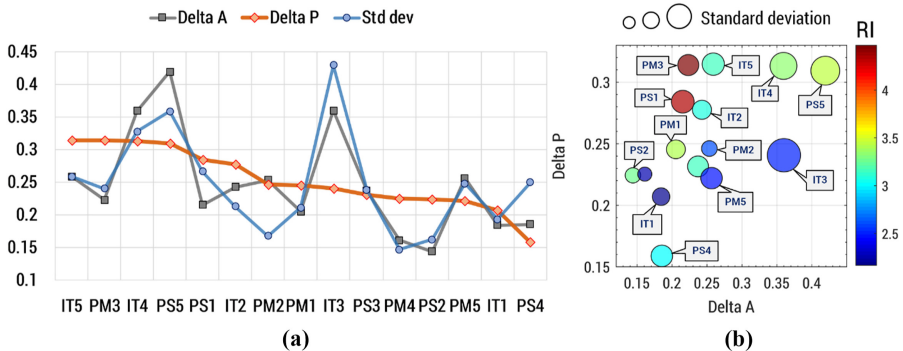


Figure 7. Uncertainties reflected by Δ_A and Δ_P in comparison with standard deviation

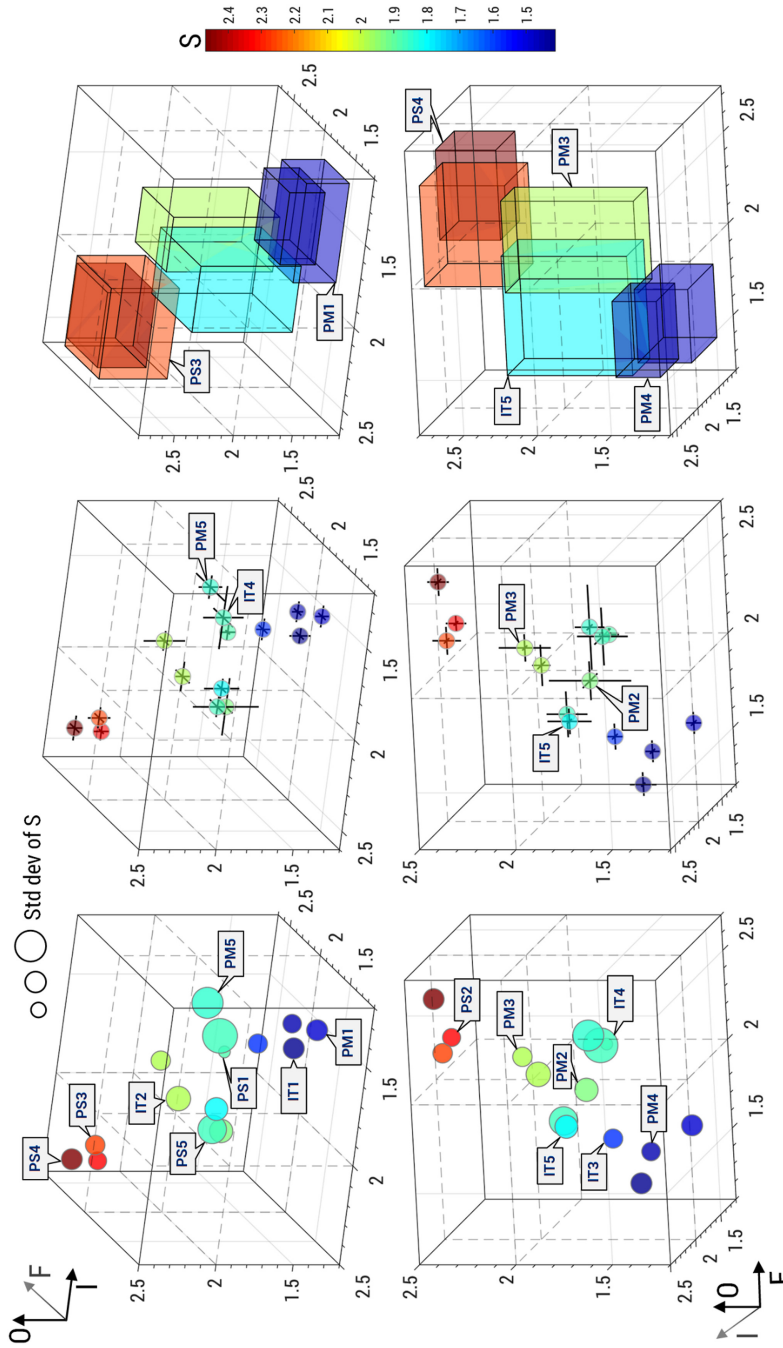


Figure 8. Results of consequence mapping results of Pathway 2

6. Conclusion

This paper presents a well-structured and versatile methodological framework for CSORA. The framework is built upon a solid theoretical basis, featuring updated understandings about risk and container shipping supply chain. Expressing and handling uncertainties and ensuring the reliability and usefulness of risk analysis results are the framework's focused objectives. The empirical study found that operational costs, especially fuel costs, are still significant with Vietnam's domestic container fleet mainly due to limited mitigation/prevention strategies, adaptation capability, competitive market and instability of the energy landscape under multiple factors. While the physical flow's overall risk level is high, information risks have a higher chance of being over- or under-estimated. Though posing a moderate to low risk level, uncertainty indicators advise a high level of uncertainty of information risks, suggesting further analyses into their causal factors and consequences, especially in a more connected, automated supply chain.

To the container shipping literature, the framework provides researchers with a theoretical basis to conduct QRA. CSORA is a versatile tool that can deliver intersubjective and meaningful insights into the CSOR situation. The empirical study showed that the framework enables the addressing of uncertainties. To the policy-makers, the framework is capable of incorporating multiple units of analysis (e.g. container shipping service providers) in different scales (e.g. national and regional) and sectors (e.g. short-sea and deep-sea shipping) to create a bird-view depiction of CSORs for strategic policy design.

The proposed framework needs more applications to prove its functionality and reliability as a CSOR research platform. A network module will be developed to consider the causal relationships between DEs, allowing multiple-event scenario analysis. Building a risk network can return a comprehensive model to pinpoint the most important root causes that need to be addressed. The dynamicity of CSORs is another improvable aspect. While it is suspected, little attention has been paid to investigate the fluctuation/mutation through time and disruptive changes of CSORs. It is important to understand the risk implication of factors, such as deglobalization (e.g. trade war), disruptive policies (e.g. IMO 2020 sulfur cap) and climate-changing, technological applications (e.g. blockchain and automation).

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Corresponding author

Son Nguyen can be contacted at: son.nguyen@utas.edu.au

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