# CMS RESEARCH UPDATES JULY 2018

**March 2018 – July 2018**

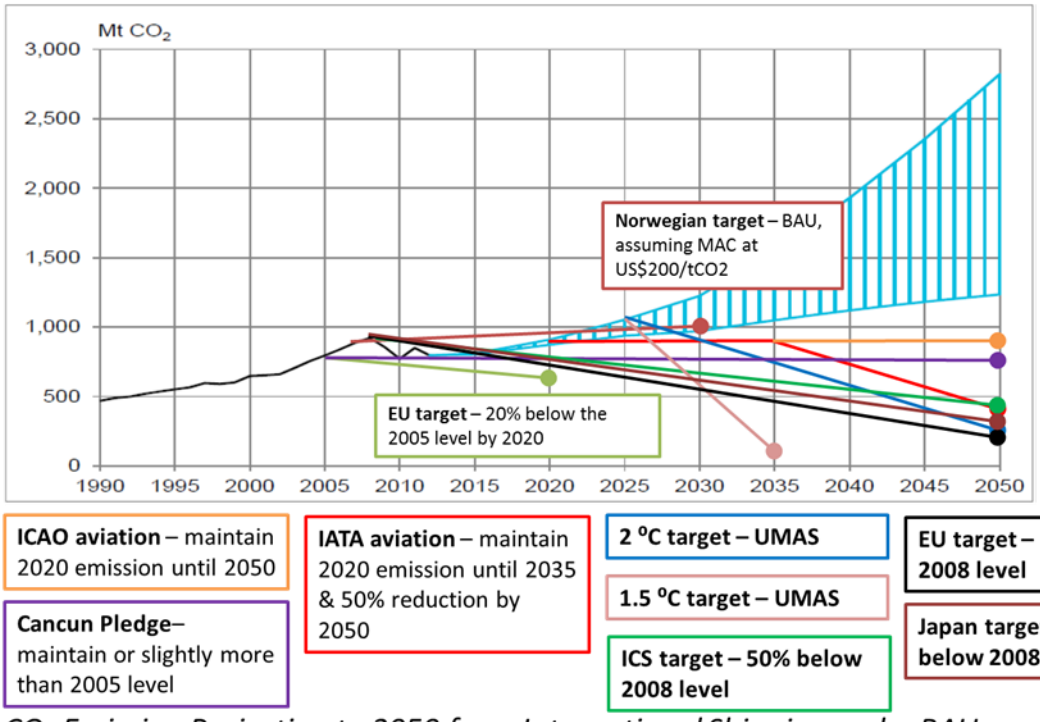
## Research Highlight 1: $CO_2$ Emission Trend and Reduction Efforts From International Shipping, by Research Fellow Dr. Sou Weng Sut (Track Leader: Associate Professor NG Szu Hui)

### Introduction

International shipping was estimated to have contributed to about 2.2% of the global emissions of carbon dioxide (CO2) in 2012 (IMO, 2014). Although it is the most energy efficient mode of mass, according a recent report by European Parliament (2015), the CO2 emission shares in global CO2 emissions may rise substantially to 17% for maritime transport by 2050, if action to combat climate change is further postponed.

Despite international shipping being excluded from the Paris Agreement which aims to limit global warming to well below 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C , the International Maritime Organization (IMO) is developing its own strategy to reduce GHGs from ships.

In recognition of the magnitude of the climate change challenge and the importance of global action to address it, various studies have proposed different emission reduction targets for international shipping.




*$CO_2$ Emission Projection to 2050 from International Shipping under BAU scenarios by 3rd IMO GHG Study 2014 and Various Proposed Reduction Targets by Different Countries / Organisations*

### Levels of Ambition Set Forthy by IMO

According to the latest IMO MEPC 72 meeting held in April 2018, IMO adopted the Initial IMO Strategy on reduction of GHG emission from ships. The Initial Strategy is included in the annex to resolution MEPC.304(72). Section 3 of the Initial Strategy sets forth its levels of ambition and guiding principles.

## Research Highlight 1: $CO_2$ Emission Trend and Reduction Efforts From International Shipping, by Research Fellow Dr. Sou Weng Sut (Track Leader: Associate Professor NG Szu Hui)

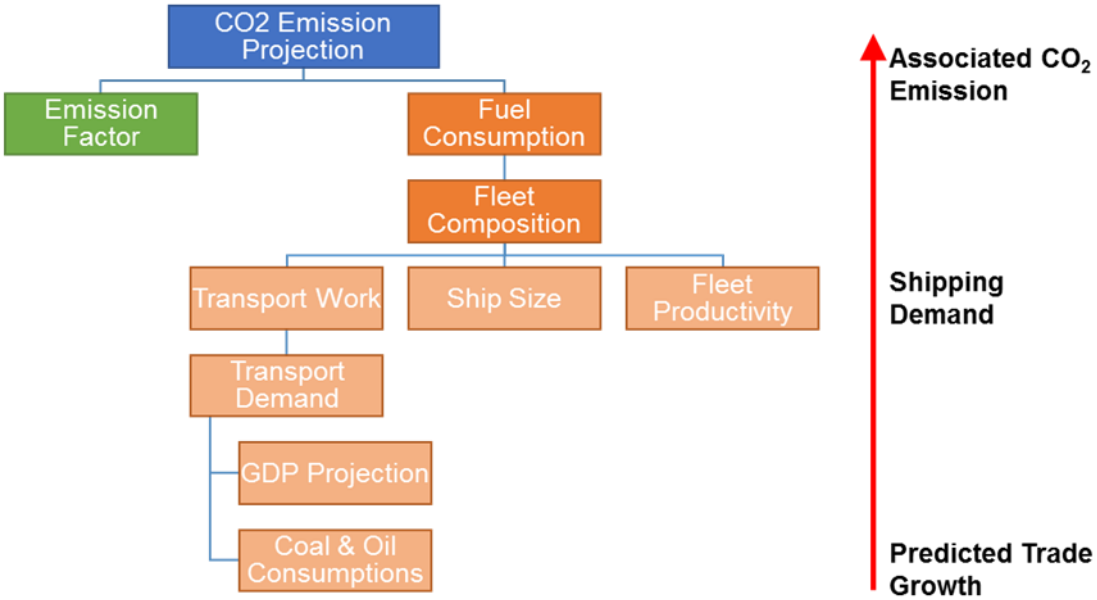
### Levels of Ambition Set Forth by IMO

Levels of ambition:

1. carbon intensity of the ship to decline through implementation of further phases of the energy efficiency design index (EEDI) for new ships
2. carbon intensity of international shipping to decline
   - to reduce CO2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and
3. GHG emissions from international shipping to peak and decline
   - to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO2 emissions reduction consistent with the Paris Agreement temperature goals

### $CO_2$ Emission Projections

To further assess the possibility in achieving the emissions targets, CO2 emissions from international shipping is projected based on the methodology as outlined in the 3rd IMO GHG Study (IMO, 2014) and shown below, CO2 emission projection by international shipping until 2050 are estimated under Scenario RCP2.6 SSP4 and compared against the adopted emission targets.

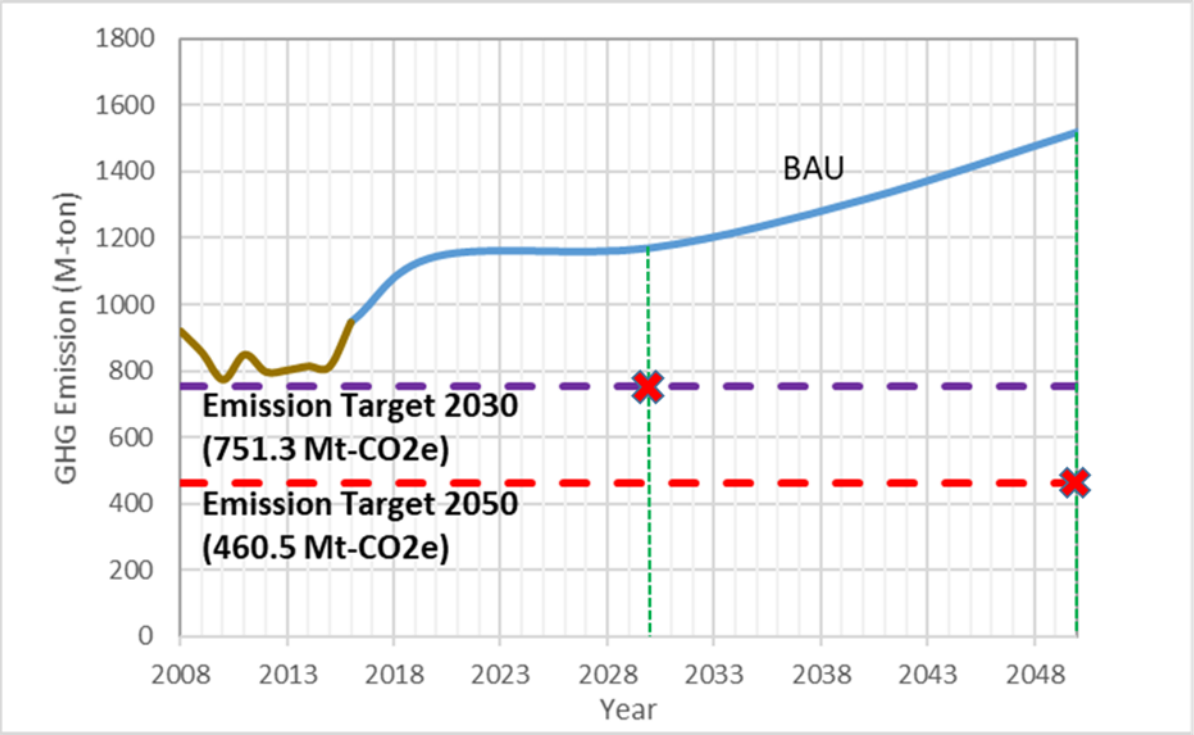



| | Scenarios |
|---|---|
| 1 | Growth in global fleet size to satisfy projected transport demand according to RCP2.6 SSP4 with a change in future vessel size distribution |

## Research Highlight 1: $CO_2$ Emission Trend and Reduction Efforts From International Shipping, by Research Fellow Dr. Sou Weng Sut (Track Leader: Associate Professor NG Szu Hui)

### $CO_2$ Emission Projections




From the two scenarios, projected CO2 emission in 2050 shoots up to more than 1500 Mt-CO2 in 2050. It could be observed that if international shipping are still operating in business as usual (BAU), the adopted emissions targets are hardly achievable. In view of this, different measures have been proposed.

### $CO_2$ Reduction Efforts From International Shipping

In recognition of the magnitude of the climate change challenge and the importance of global action to address it, IMO has been energetically pursuing the development and implementation of measures to address greenhouse gas (GHG) emissions from international shipping.

Four major types of energy efficiency measures being implemented/proposed:

1. Energy Efficiency Design Index (EEDI) regulation and Ship Energy Efficiency Management Plan (SEEMP), with effective from 1st January 2013
2. Technical and Operational (T&O) Measures
3. Alternative Fuels
4. Market-based Measures (MBMs)

### Potential $CO_2$ Emission Reduction by T&O Measures

T&O measures are first ranked by Impact Readiness Level (IRL), then marginal abatement costs (MACs), which are widely used in assessing the cost effectiveness of energy efficiency measures, are computed.

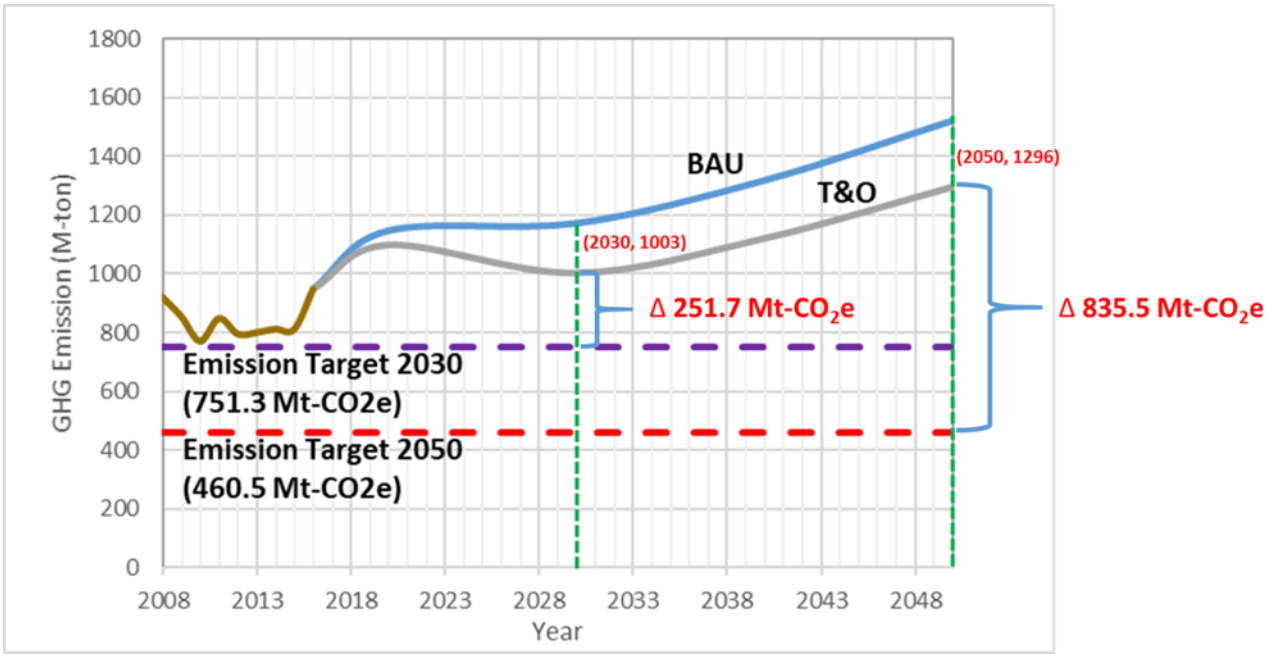
## Research Highlight 1: $CO_2$ Emission Trend and Reduction Efforts From International Shipping, by Research Fellow Dr. Sou Weng Sut (Track Leader: Associate Professor NG Szu Hui)

### Potential $CO_2$ Emission Reduction by T&O Measures

In 2030, assuming 60% adoption of T&O measures with high TRL-MAC<0 on vessels in international shipping, potential GHG emission reduction range between 114 - 224 Mt-CO2e (Expected Mean: 169 Mt-CO2e), depending on the range of HFO fuel price, abatement potential, CapEx & OpEx estimate of each measure.

Furthermore, in 2050, assuming the 60% adoption of T&O measures with all TRL-MAC<0, potential GHG emission range between 162-288 Mt-CO2e (Expected Mean: 225 Mt-CO2e), depending on the range of HFO fuel price, abatement potential, CapEx & OpEx estimate of each measure.

Results show that, if only relying on T&O measures as the sole mitigation efforts for emission reduction in international shipping, the adopted targets could hardly be achieved, as shown in figure below. There is a gap of over 250 Mt-CO2 and over 830 Mt-CO2 in 2030 and 2050 respectively.




### Future Works on Other Measures

In order to overcome the gaps in achieving the targets, usage of alternative fuels (i.e. low carbon emission fuel or zero carbon emission fuel) and also implementation of market-based measures become increasingly significant.

### Acknowledgement

This research project is in collaboration with Nanyang Technological University (NTU) and is supported by the Singapore Maritime Institute (SMI).

## Research Highlight 2: Modeling Ship Collision Risk based on Dynamic Ship Domain and COLREGS, by Research Engineer Wei Xiaoyang (Track Leader: Professor MENG Qiang)

### Objectives and Contributions

The objective of this study is to develop a Quantified Risk Assessment (QRA) model in order to assess the ship collision risk based on dynamic ship domain. To achieve this objective, it is required to approximate the dynamic ship domain under possible effective factors. Two novel approaching parameters between ships in an encounter are presented to indicate the spatio-temporal proximity degree for ships, and are derived analytically. An ordered probit model of the risk of collision is developed for measuring collision risk in a waterway. The model is calibrated and evaluated by using several goodness-of-fit statistics. The proposed ship collision risk model is illustrated for Singapore Strait based on the Automatic Identification System (AIS) data from Maritime and Port Authority of Singapore (MPAS).

The contribution of this study is twofold. First, the proposed QRA model can be further embedded into Collision Avoidance Systems (CAS), providing risk assessment, early-warning as well as decision-making support for navigation in special environmental conditions. Second, the combination of the proposed QRA model and ship traffic simulations could be able to check the viability of new navigational safety strategy which will be implemented in fairways, evaluate the feasibility of some physical changes in a waterway, estimate the maximum capacity of the channel, etc., by identifying whether the collision risk exceed the acceptable risk levels or not.

### Construction of Dynamic Ship Domain

Without loss of generality, assuming the effects of LOA and speed on ship domain are generally non-linear (Śmierzchalski & Michalewicz, 2000; Kijima & Furukawa, 2003). Therefore, a suitable formulation of the LOA or speed function might be a quadratic function defined as:

$$\alpha,\beta_i(m)=\lambda_i^{\alpha,\beta}(m)^2+\mu_i^{\alpha,\beta}(m)+\gamma_i^{\alpha,\beta} \quad (1)$$

Where $m = v, L$; $\lambda$, $\mu$ and $\gamma$ are the parameters to be determined under different conditions of speeds and LOA, which are studied as follows.

As shown in Fig. 1, the approach to calibrate the dynamic ship domain model includes three steps, namely (i) ship movement data preparation, (ii) OS and TS mapping and (iii) ship domain boundary determination, which are illustrated by an algorithmic framework in Table 1.

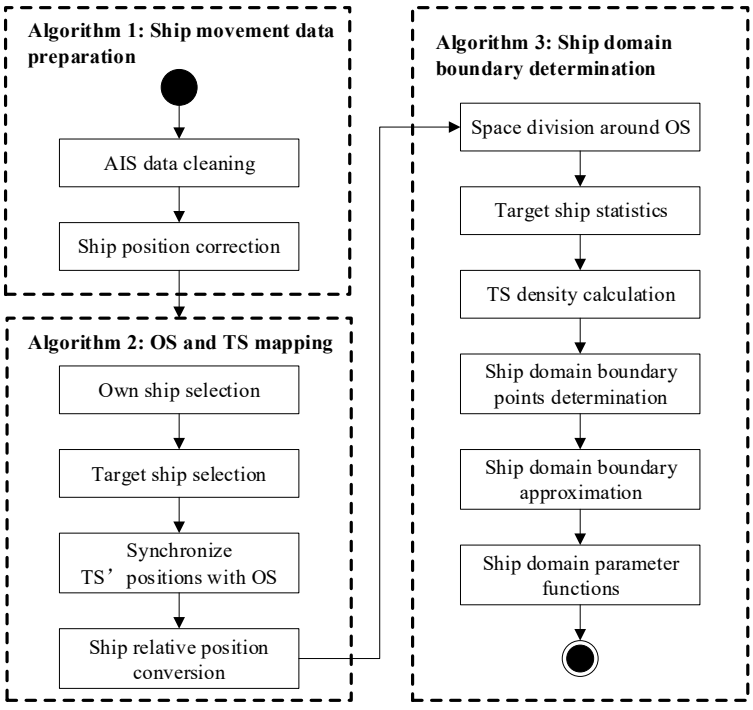



Fig. 1. Calibration framework for dynamic ship domain.

## Research Highlight 2: Modeling Ship Collision Risk based on Dynamic Ship Domain and COLREGS, by Research Engineer Wei Xiaoyang (Track Leader: Professor MENG Qiang)

### Construction of Dynamic Ship Domain

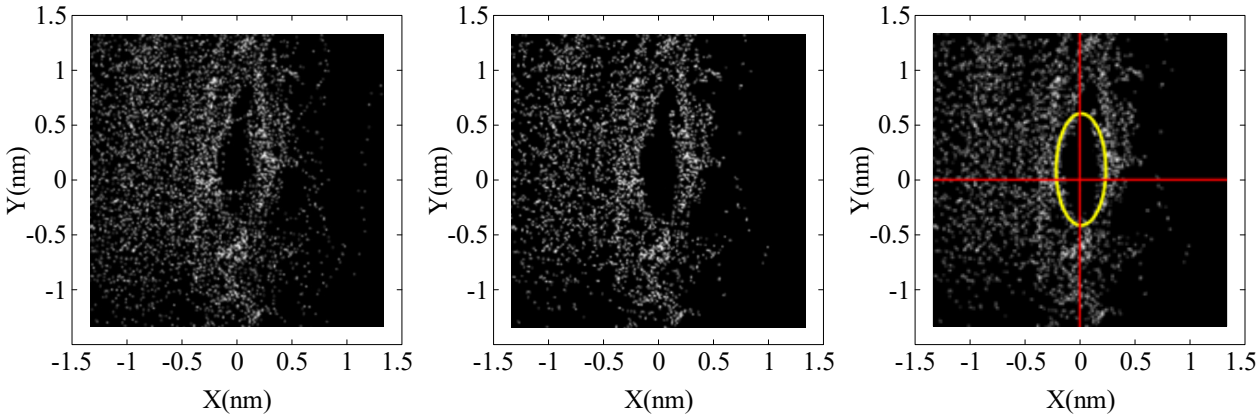



Fig. 2. An empirical ship domain from AIS data, (a) Rough AIS data, (b) Corrected AIS data, (c) Ship domain boundary determination.

The relationship between ship domain parameters and ship speed:

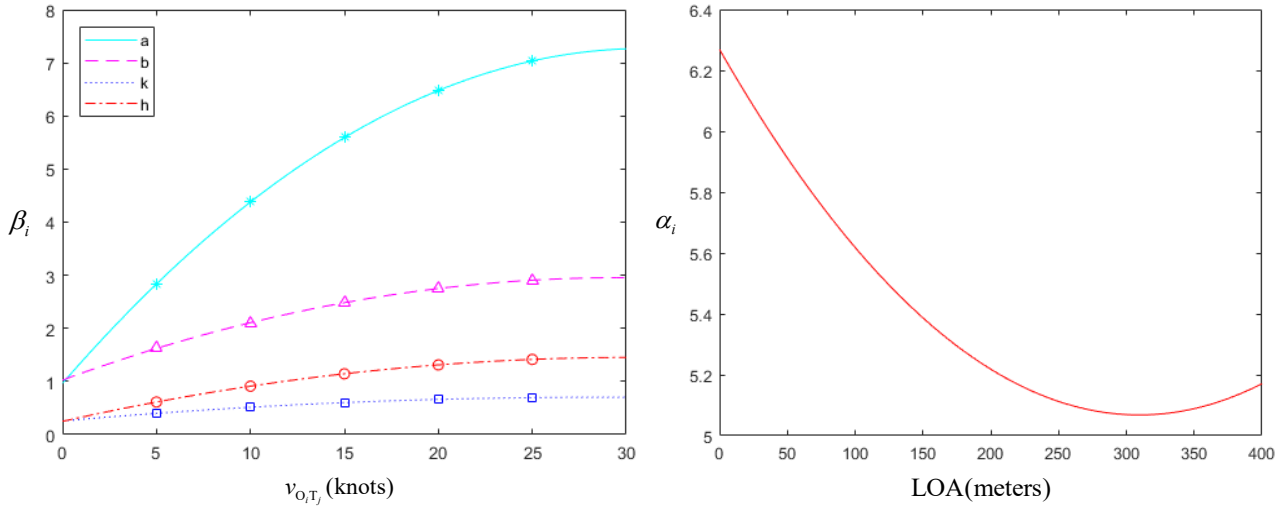



Fig. 3. Effects on ship domain parameters, (a) speed functions, (b) LOA function.

Domain size increasing with speed initially but tapering off at higher speeds., the size of the zero-speed domain can also be determined by supposing.

### Risk Assessment Model

I. Modeling collision risk

Since the risk levels used in the scale are ordered in nature, the ordered probit model is appropriate to treat such data, and is formulated as a latent (i.e., unobserved) variable framework is this study:

$$\zeta_{eij} = \beta \mathbf{X}_{eij} + \varepsilon_{eij} \quad (2)$$

## Research Highlight 2: Modeling Ship Collision Risk based on Dynamic Ship Domain and COLREGS, by Research Engineer Wei Xiaoyang (Track Leader: Professor MENG Qiang)

### Risk Assessment Model

where $\zeta_{eij}$ is a continuous latent variable measuring collision risk during the encounter $e$ between ship $O_i$ and ship $O_j$, under approaching parameters $\mathbf{X}_{eij}$; $\beta$ is the vector of regression coefficients; $\varepsilon_{eij}$ is the random error term.

Due to the fact that it is difficult to observe the accident severity exactly by using the variable $\zeta_{eij}$, which is mapped on to an observed and coded discrete variable $Z_{eij}$, which represents the risk levels used in the scale:

$$Z_{eij} = \tau \text{ if } \lambda_{\tau-1} \le \xi_{eij} \le \lambda_{\tau}; \text{ for } \tau=1 \text{ to T} \tag{3}$$

where $T$ is number of ordinal categories, and the threshold values ( $\lambda$ ) are unknown parameters describing the boundaries of risk levels.

Based on the normality assumption of the error term, the probability of risk level $\tau$ for given $\mathbf{X}_{eij}$ can be predicted:

$$\begin{aligned}\Pr\left(Z_{eij}=\tau \mid \mathbf{X}_{eij}\right) &= \Pr\left(\lambda_{\tau-1} \le \xi_{eij} \le \lambda_{\tau}\right) = \Pr\left(\varepsilon_{eij} \le \lambda_{\tau} - \beta\mathbf{X}_{eij}\right) - \Pr\left(\varepsilon_{eij} \le \lambda_{\tau-1} - \beta\mathbf{X}_{eij}\right) \\ &= \Phi\left(\lambda_{\tau} - \beta\mathbf{X}_{eij}\right) - \Phi\left(\lambda_{\tau-1} - \beta\mathbf{X}_{eij}\right)\end{aligned} \tag{4}$$

$$\sum_{\tau=1}^{T} \Pr\left(Z_{eij}=\tau \mid \mathbf{X}_{eij}\right) = 1 \tag{5}$$

Collision risk in an encounter $e$ between ship $O_i$ and ship $O_j$ can then be computed:

$$C_{eij} = \sum_{\tau=1}^{T} RS_{\tau} \times \hat{\Pr}\left(Z_{eij}=\tau \mid \mathbf{X}_{eij}\right) \tag{6}$$

where $C_{eij}$ is the maximum collision risk during an interaction between the own ship $O_i$ and the target ship $T_j$. $RS_{\tau}$ represents the probability of collision for risk level $\tau$. $\mathbf{X}_e$ is a vector of approaching indicators (i.e., $f_N$ and $t_{f_N}$).

### Model Calibration

The likelihood ratio statistics of all models (e.g., 243.4 and 187.8 for Container ship-Day and Container ship-Night models respectively) are well above the critical value for significance at 99% level of significance, which implies that

**Research Highlight 2: Modeling Ship Collision Risk based on Dynamic Ship Domain and COLREGS, by Research Engineer Wei Xiaoyang (Track Leader: Professor MENG Qiang)**

## Model Calibration

the models have reasonable good fit. The McKelvey and Zavoina's $R^2$ values (e.g., 0.58 and 0.47 for Container ship-Day and Container ship-Night models respectively) also indicate sufficient predictive power for all models. Both $f_N$ and $t_{f_N}$ show significant positive association with the latent variable in all models (e.g., for Container ship-Day model: $\beta_{f_N}=0.27, p<0.001$; $\beta_{t_{f_N}}=0.12, p<0.001$;). This indicates that collision risk decreases if $f_N$ and $t_{f_N}$ increase.

By utilizing the estimated regression, risk of collision in an interaction can be obtained. This is illustrated for $f_N=0.5$ and $t_{f_N}=2$ minutes, as shown in Table 1. A comparison of the risks with the scores of the risk levels (presented in Table 2) of all models shows that the risks fall in the HR range (e.g., for Container ship-Day model: risk = 0.86 < $RS_{HR}=0.91$), which is expected for such small values of $f_N$ and $t_{f_N}$. Risks in night conditions are also found to be higher than those in the day, e.g., the risk in night increases by 1.3% for container ship. It is sensible to observe higher risk in night because of the restricted visibility and lack of visual perception in the night condition.

Table 1. Estimated Risk Level Probabilities and Collision Risks (at $f_N=0.5$, $t_{f_N}=2$ minutes)

| Vessel Type | Day | | | | | | Night | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Predicted probability from model estimates | | | | | Col. risk | Predicted probability from model estimates | | | | | Col. risk |
| | VHR | HR | MR | LR | SAFE | | VHR | HR | MR | LR | SAFE | |
| VC1 | 0.4099 | 0.2981 | 0.2383 | 0.0498 | 0.0040 | 0.8580 | 0.4716 | 0.3433 | 0.1298 | 0.0507 | 0.0045 | 0.8690 |
| VC2 | 0.3205 | 0.5857 | 0.0935 | 0.0003 | 0.0000 | 0.9020 | 0.5495 | 0.4372 | 0.0133 | 0.0000 | 0.0000 | 0.9280 |
| VC3 | 0.4313 | 0.4216 | 0.1159 | 0.0296 | 0.0016 | 0.8870 | 0.5116 | 0.3925 | 0.0836 | 0.0120 | 0.0003 | 0.9000 |
| VC4 | 0.4711 | 0.3623 | 0.1379 | 0.0269 | 0.0017 | 0.8810 | 0.5233 | 0.3484 | 0.1070 | 0.0191 | 0.0022 | 0.9010 |

VC1: Container ship; VC2: RoRo & Panssenger; VC3: Dangerous cargo ship; VC4: Common cargo ship
VHR: Very High Risk; HR: High Risk; MR: Moderate Risk; LR: Low Risk

Table 2. Risk Scores for Risk Levels

| Vessel Type | Day | | | | | Night | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $RS_{VHR}$ | $RS_{HR}$ | $RS_{MR}$ | $RS_{LR}$ | $RS_S$ | $RS_{VHR}$ | $RS_{HR}$ | $RS_{MR}$ | $RS_{LR}$ | $RS_S$ |
| VC1 | 1 | 0.9138 | 0.6679 | 0.3309 | 0 | 1 | 0.8914 | 0.5701 | 0.3000 | 0 |
| VC2 | 1 | 0.8918 | 0.6346 | 0.3353 | 0 | 1 | 0.8483 | 0.6044 | 0.3036 | 0 |
| VC3 | 1 | 0.9066 | 0.5515 | 0.3147 | 0 | 1 | 0.8640 | 0.5404 | 0.3010 | 0 |
| VC4 | 1 | 0.8892 | 0.5803 | 0.3033 | 0 | 1 | 0.8623 | 0.5299 | 0.2538 | 0 |

$RS_i$ : Risk score for $i$ level; $i$ =Very High Risk, High Risk, Moderate Risk, Low Risk or Safe

## Research Highlight 2: Modeling Ship Collision Risk based on Dynamic Ship Domain and COLREGS, by Research Engineer Wei Xiaoyang (Track Leader: Professor MENG Qiang)

### Procedure of Measuring Ship Collision Risk

Sufficiently large numbers of conflict observations are necessary in order to obtain a statistically fitted distribution of $C_{eij}$. Uncertainties in the estimated parameters of the distributions could be reduced with increased number of observations. Based on a preliminary analysis, about 120 million records of AIS data during one-month period in Singapore Strait are taken for this study. These data include ships' positions in coordinates, speeds, courses, sizes, ship types and numeric identities. The kinematic information is usually updated at time intervals of few seconds depending on traffic characteristics, thus the data provides detailed trajectories of ships. A block diagram showing the steps of a developed program is presented in Fig. 4.

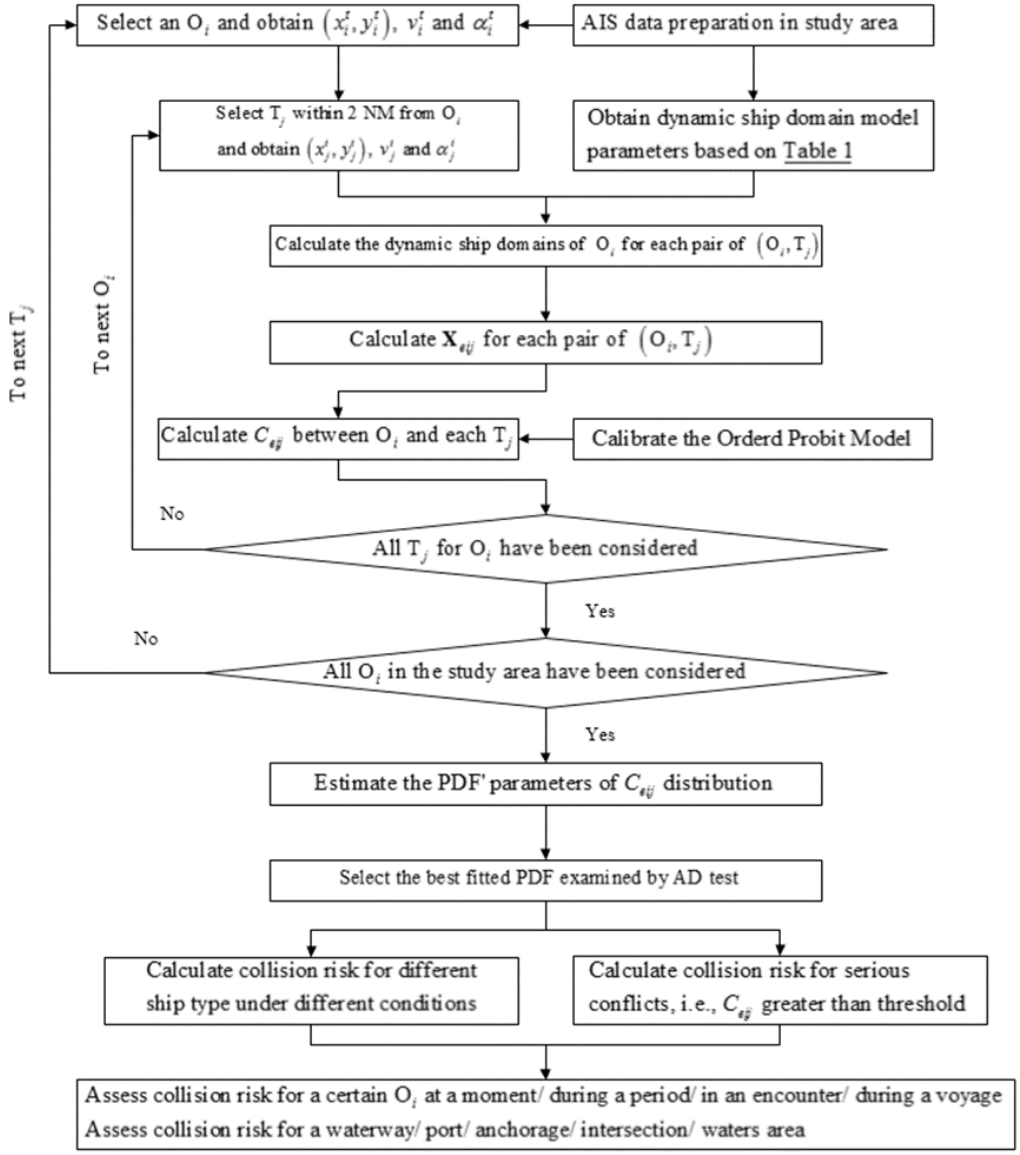



Fig. 4. Block diagram of measuring collision risk.

## Research Highlight 2: Modeling Ship Collision Risk based on Dynamic Ship Domain and COLREGS, by Research Engineer Wei Xiaoyang (Track Leader: Professor MENG Qiang)

### Procedure of Measuring Ship Collision Risk

The input information necessary for the analysis are the positions, speeds, courses and lengths of ships in the study area. By utilizing the input data, the proximity indicators $\mathbf{X}_{eij}$ values are calculated for all possible vessel pairs in a waterway in consideration. To form the pairs, one certain ship or one-by-one ship in the database is kept as own vessel, while the other ships within 2 nautical miles from the own ship are considered as target vessels.

By using the calibrated ordered probit model, the $C_{eij}$ values are obtained for all vessel pairs in the database. Having calculated $C_{eij}$ values for all vessel pairs in the study area, the PDF of $C_{eij}$ is obtained by examining fitness of the proposed distributions with observed values of $C_{eij}$. Having estimated the parameters in $\Phi(\tau)$, collision risk is measured in study areas within a time period under day and night conditions.

### Results and Discussions

I. Validation using AIS data

With the processing method presented in Fig. 4, the ship collision risk assessment for Singapore Strait can be conducted based on historical AIS data, and the spatial distribution of collision risk is presented in Fig. 5.

It clearly shows that the riskiest area is around LEG 4W and LEG 12 E, which has long been well recognized as the geographical chokepoints of the Singapore Strait. One possible reason for the high collision risk in 3W and 13E might be that there are a large number of ship acceleration and deceleration maneuvers within this area. According to *Passage Planning Guide: Malacca & Singapore Straits* (SIGTTO, 2008), the ships commence reducing speed to 12 knots in Legs 3W and 8E. Ships in Legs 7W and 13E are about to increase speed over 12 knots if conditions are suitable, which produces a larger number of overtaking conflicts.

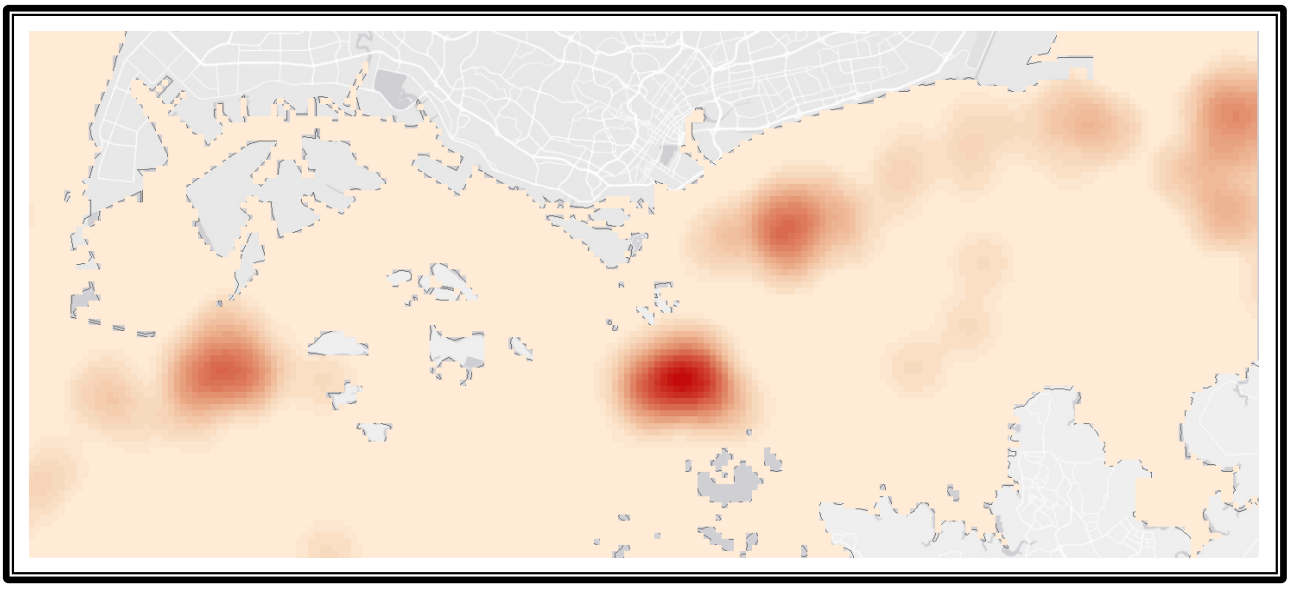


Fig. 5. Spatial distribution of collision risk in Singapore Strait.

## Research Highlight 2: Modeling Ship Collision Risk based on Dynamic Ship Domain and COLREGS, by Research Engineer Wei Xiaoyang (Track Leader: Professor MENG Qiang)

### Results and Discussions

These findings are consistent with the collision incident statistics in Singapore area (2010-2014) as shown in Fig. 6, and correspond with the results by other studies (Qu et al, 2011; Weng et al., 2012; Chai et al., 2017).

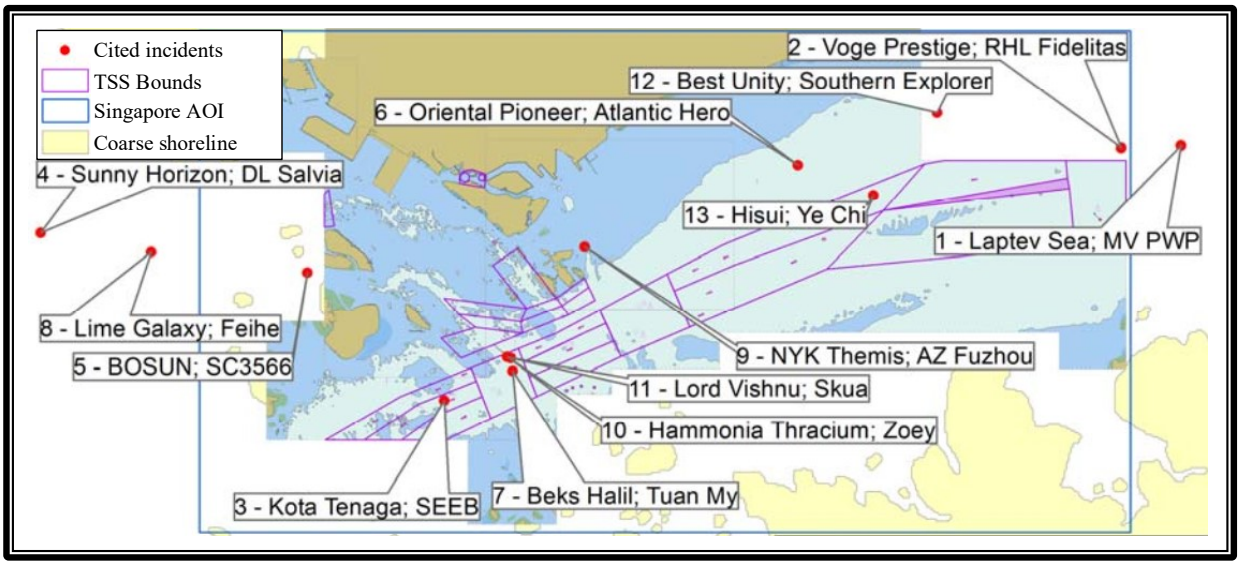



Fig. 6. Identified collision incidents in Singapore area (2010-2014).

II. Validation based on perception survey data

To validate the proposed risk assessment model, the measured collision risks for day and night conditions is compared with those perceived by captains sailing through Singapore Strait usually. The age of respondents ranged from 38 to 61 years with a mean and standard deviation of 49.0 years and 9.8 years respectively. The respondents had an average 15.3 years' experience as captains with a standard deviation of 10.9 years. Correlations between the measured risks and the perceived risks in the waterways are evaluated (shown in Fig. 7).

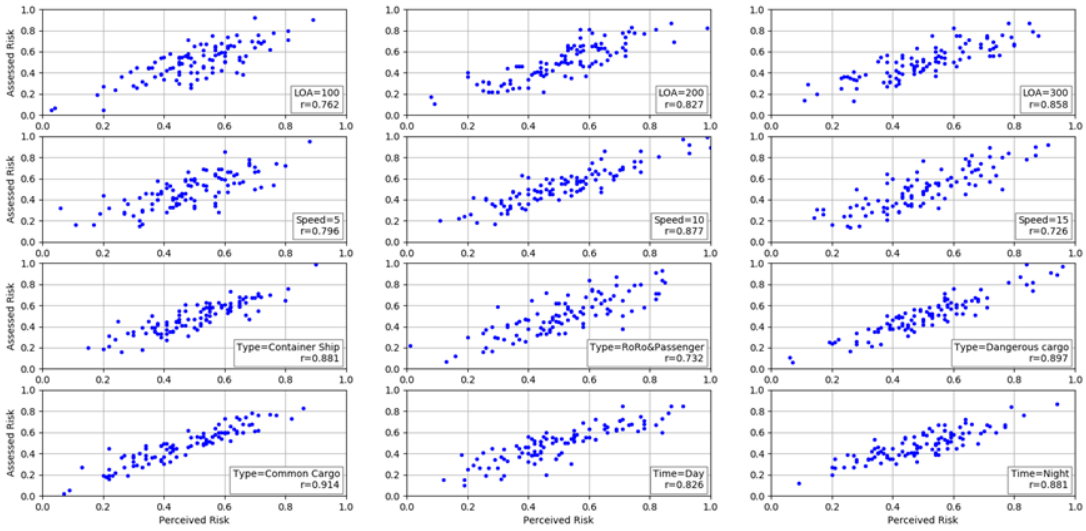



Fig. 7. Correlations between measured risks and perceived risks

**Research Highlight 2: Modeling Ship Collision Risk based on Dynamic Ship Domain and COLREGS, by Research Engineer Wei Xiaoyang (Track Leader: Professor MENG Qiang)**

## Results and Discussions

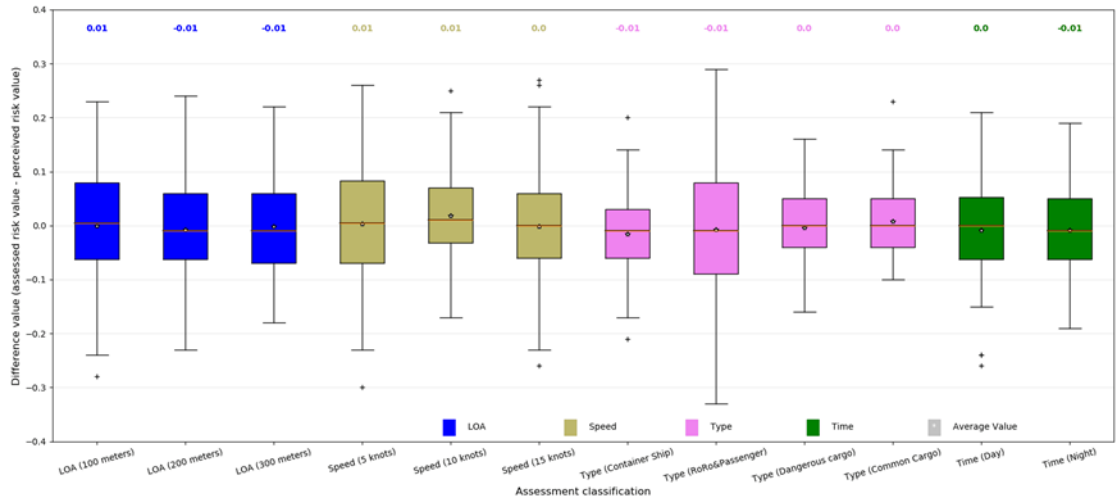



Fig. 8. Distribution of difference values between measured risk and perceived risk.

The correlations between the measured risks and the average perceived risks about LOA, ship speed, ship type and day/night are shown graphically in Fig. 7. Results show that the $p_{MR,PR}$ values for LOA (100m), LOA (200m) and LOA (300m) are 0.762, 0.827 and 0.858 respectively. For speeds, the coefficients are found as 0.796 (5knots), 0.877 (10knots) and 0.726 (15knots) respectively. The corresponding coefficients for ship type are found as 0.881 (Container ship), 0.732 (RoRo & Passenger), 0.897 (Dangerous cargo ship) and 0.914 (Common cargo ship). With respect to day and night, the correlation coefficients are 0.826 and 0.881 respectively. The reasonably high correlations and acceptable differences between measured and perceived risks imply that the proposed model is valid for collision risk assessment under a variety of conditions.

## Conclusion

The paper changes the above state of things by presenting a solution to collision risk assessment based on dynamic ship domain violation. Two domain-based approaching parameters - $f_{\mathrm{N}}$ and $t_{f_{\mathrm{N}}}$ - are introduced and formulas for both of them are derived. The derivations assume elliptic domain model, though it is possible to use them for other shapes if a simple approximation is performed first.

Possible systems where the proposed approaching parameters and risk assessment model could be applied include collision avoidance systems (CAS), with: a. Cautions generation for passing by proximity ships; b. Collision risk assessment for predicted maximum domain violations and remaining time; c. Guides raised for situations demanding imminent actions.

## Published Technical Papers (with Abstracts)

1. **H Wang and BW Ang (2018), Assessing the role of international trade in global $CO_2$ emissions: An index decomposition analysis approach.** ***Applied Energy, Volume 218, Pages 146-158.***

**Abstract:**

Trade-related CO2 emissions are an important component in global emissions. Understanding the role of international trade in emissions is of direct relevance to global and national emission reductions, particularly for major exporters and importers. In the literature, the issue has seldom been studied using index decomposition analysis (IDA), which is a popular tool in assessing growth in national-level CO2 emissions. In this paper, based on a multi-region I-O analysis, we introduce three inter-linked IDA models to quantify the impacts of trade on the production-based emissions, the consumption-based emissions, and the emission balance of economies, respectively. A salient feature of the models, when applied together, is that they can help to assess the role of trade and the emission performance of economies from multiple perspectives. We discuss the relevant methodological issues as well as the advantages and limitations of the models. We then apply the models to evaluate the impact of international trade on changes in global CO2 emissions from 1995 to 2009. It is found that while the growing trade volume drove up the total emissions, changes in the emission intensity and goods composition related to trade led to some degree of emission mitigation, particularly after 2005.

2. **BW Ang and Tian Goh (2018), Bridging the gap between energy-to-GDP ratio and composite energy intensity index.** ***Energy policy, Volume 119, Pages 105-112.***

**Abstract:**

The energy-to-GDP ratio (EGR) is an indicator often used as a proxy for economy-wide energy efficiency in policy formulation and analysis. It is easy to compute and interpret, but its limitations as an energy efficiency indicator are also well known. Another widely used indicator is the composite energy intensity (CEI) index constructed from disaggregated energy and activity data. The CEI index is seen as a better proxy for energy efficiency but it is more difficult to construct as compared to the EGR. Countries have computed and compared the two indexes and reported their divergence in capturing energy efficiency trends. While economic structure change is one explanation for the divergence, it is not the only contributing factor and the issue has not been studied in detail. This study seeks to fill the gap. It dissects and discusses the fundamentals of the two indicators, and establishes a formal linkage between them by introducing a factor termed the “activity correction” (AC) effect. A case study is presented. The significance and policy implications of the AC effect are discussed.

3. **Debabrota Basu, Pierre Senellart and Stéphane Bressan (2018), BelMan: bayesian bandits on the belief--reward manifold.** ***arXiv preprint arXiv:1805.01627.***

**Abstract:**

We propose a generic, Bayesian, information geometric approach to the exploration--exploitation trade-off in multi-armed bandit problems. Our approach, BelMan, uniformly supports pure exploration, exploration--exploitation, and two-phase bandit problems. The knowledge on bandit arms and their reward distributions is summarised by the barycentre of the joint distributions of beliefs and rewards of the arms, the \emph{pseudobelief-reward}, within the beliefs-rewards manifold. BelMan alternates \emph{information projection} and \emph{reverse information projection}, i.e., projection of the pseudobelief-reward onto beliefs-rewards to choose the arm to play, and projection of the resulting beliefs-rewards onto the pseudobelief-reward. It introduces a mechanism that infuses an exploitative bias by means of a \emph{focal distribution}, i.e., a reward distribution that gradually concentrates on higher rewards. Comparative performance evaluation with state-of-the-art algorithms shows that BelMan is not only competitive but can also outperform other approaches in specific setups, for instance involving many arms and continuous rewards.

## Published Technical Papers (with Abstracts)

4. **Yagub Alipouri, Mohammad Hassan Sebt, Abdollah Ardeshir and Weng Tat Chan (2017), Solving the FS-RCPSP with hyper-heuristics: A policy-driven approach.** ***Journal of the Operational Research Society, Pages 1-17.***

**Abstract:**

In this paper, a problem in the area of scheduling, namely Fuzzy Stochastic Resource-Constrained Project Scheduling Problem (FS-RCPSP), is addressed. Like the original Resource-Constrained Project Scheduling Problem (RCPSP), the objective is to minimise the expected makespan of the project subject to precedence and resource constraints. However, due to mixed uncertainty comprising fuzziness and randomness in the estimates of activity durations, the makespan is a fuzzy stochastic number. Recognising both fuzziness and randomness in activity durations results in more robust schedules but the scheduling problem is harder to solve. A hyper-heuristic, named Self-adaptive Differential Evolution to Scheduling Policy (SADESP) is proposed to address this issue. SADESP has two key modules: (1) a module (policyEvolver) which evolves scheduling policy and (2) a dynamic scheduling procedure (dScheduler) which makes scheduling decisions using a particular scheduling policy. The performance of SADESP is benchmarked against CPLEX across an extensive set of 960 problems created with ProGen – a standardised problem generator for creating benchmark problems in scheduling. The results returned by SADESP for FS-RCPSP are very encouraging, both in terms of accuracy and computational performance.

5. **Xin Jia Jiang, Yanhua Xu, Chenhao Zhou, Ek Peng Chew and Loo Hay Lee (2018), Frame Trolley Dispatching Algorithm for the Frame Bridge Based Automated Container Terminal.** ***Transportation Science, Volume 52, No. 3.***

**Abstract:**

This paper studies the container handling process for a newly designed container terminal, known as the Frame Bridge based Automated Container Terminal (FB-ACT). The system was shown to be an effective solution to the next generation container terminal, but its efficiency depends on the dispatching of frame trolleys (FTs), which transport containers along the apron. We address the FT dispatching problem to ensure conflict-free movements, while considering the handshakes with other devices in the system. A mixed-integer programming (MIP) model is formulated to minimize the make span considering FT conflicts and handshakes. An algorithm based on filtered beam search is developed to solve the problem. In this algorithm, two filtering approaches are used to guide the search for beam nodes at each level. The first approach uses a surrogate model to effectively screen out the less promising nodes. Then, the second approach uses a reduced MIP model to further identify the beam nodes for the next level. Numerical experiments show that our proposed algorithm yields near-optimal solutions in small-scale problems. In large-scale problems, our algorithm significantly outperforms two other algorithms based on first come, first served (FCFS) or FCFS with dedicated vehicle assignment. Some interesting insights about the FB-ACT system are also shown in the study.

6. **Xiaohu Qian, Min Huang, Wai-Ki Ching, Loo Hay Lee and Xingwei Wang (2018), Mechanism design in project procurement auctions with cost uncertainty and failure risk.** ***Journal of Industrial & Management Optimization, Pages 1-34.***

**Abstract:**

Project procurement has two important attributes: cost uncertainty and failure risk. Due to the incomplete feature of such attributes, a novel mechanism incorporating contingent payments and cost sharing contracts is proposed for the buyer. Constructing models of bid decisions for risk averse and risk neutral suppliers, respectively, closed-form solutions of optimal bid prices are derived. By investigating the properties of bid prices in a first-score sealed-bid reverse auction, we find that when the degree of risk aversion or the variance of unpredictable cost is

## Published Technical Papers (with Abstracts)

sufficiently small, bid prices of risk averse suppliers could be lower than those of risk neutral suppliers. Yet risk averse suppliers always bid higher than risk neutral suppliers in a second-score sealed-bid reverse auction. An interesting result verified by numerical experiments is that the classical revenue equivalence theorem no longer holds for the proposed mechanism if suppliers involve risk averse behavior. In this case, the buyer's best choice is to adopt a first-score sealed-bid reverse auction. We also provide decision support for the buyer to achieve optimal expected profit.

7. **Liye Zhang, Qiang Meng, Zhe Xiao, Xiuju Fu (2018), A novel ship trajectory reconstruction approach using AIS data.** ***Ocean Engineering, Volume 159, Pages 165-174.***

**Abstract**:

AIS data plays an increasingly important role in collision avoidance, risk evaluation, and navigation behavior study. However, the raw AIS data contains noise that can result in wrong conclusions. We propose a multi-regime vessel trajectory reconstruction model through three-steps processing, including (i) outliers removal, (ii) ship navigational state estimation and (iii) vessel trajectory fitting. This model allows for vessel trajectory reconstruction in different navigation states, namely hoteling, maneuvering, and normal-speed sailing. The normal-speed navigation trajectory is estimated with a spline model, which can fit any types of the trajectory even with circles. Then, the proposed model is tested and compared with other three popular trajectory reconstruction models based on a large AIS dataset containing the movement of more than 500 ships in Singapore Port. The results show that the proposed model performs significantly better than the linear regression model, polynomial regression model, and weighted regression model. The proposed model can decrease the abnormal rate of speed, acceleration, jerk and ROT (Rate of Turn) from 43.42%, 10.65%, 59.25%, 50.33%–0.00%, 0.00%, 17.28% and 15.81%, respectively. More importantly, the navigational behavior, such as turning operation, could be clearly shown in the trajectory reconstructed by the proposed model.

8. **Min Xu, Qiang Meng and Zhiyuan Liu (2018), Electric vehicle fleet size and trip pricing for one-way carsharing services considering vehicle relocation and personnel assignment.** ***Transportation Research Part B: Methodological, Volume 111, Pages 60-82.***

**Abstract**:

This study proposes an interesting electric vehicle fleet size and trip pricing (EVFS&TP) problem for one-way carsharing services by taking into account the necessary practical requirements of vehicle relocation and personnel assignment. The EVFS&TP problem aims to maximize the profit of one-way carsharing operators by determining the electric vehicle fleet size, trip pricing, and strategies of vehicle relocation and personnel assignment subject to the elastic demand for the one-way carsharing services. A mixed-integer nonlinear and nonconvex programming model is first built for the EVFS&TP problem. By exploiting the unique structure of the original built model, a mixed-integer convex programming model is subsequently developed. An effective global optimization method with several outer-approximation schemes is put up to find the global optimal or ε-optimal solution to the EVFS&TP problem. A case study based on a one-way carsharing operator in Singapore is conducted to demonstrate the efficiency of the proposed model and solution method and further analyse the impact of demand, the degree of demand variation, the fixed operational cost of the vehicles as well as payment for personnel on the performance of the one-way carsharing services.

## Published Technical Papers (with Abstracts)

9. **Zhaoyang Lu and Qiang Meng (2018), Impacts of pavement deterioration and maintenance cost on Pareto-efficient contracts for highway franchising.** ***Transportation Research Part E: Logistics and Transportation Review, Volume 113, Pages 1-21.***

**Abstract:**

In a build-operate-transfer (BOT) highway project, pavement roughness progression generally has a direct impact on the highway maintenance cost and user costs. Given two common rehabilitation strategies, this study respectively investigates the optimally designed highway capacity and tolls of multi-type vehicles in Pareto-efficient contracts. Under supplementary conditions, it proves that the optimal toll revenue could fully cover the highway construction and maintenance cost in these contracts, no matter with or without the regulated traffic composition. Further extensions are made to evaluate and identify properties of the highway v/c ratio, rehabilitation period or critical roughness under the two rehabilitation strategies, respectively.

10. **Yadong Wang, Qiang Meng and Haibo Kuang (2018), Jointly optimizing ship sailing speed and bunker purchase in liner shipping with distribution-free stochastic bunker prices.** ***Transportation Research Part C: Emerging Technologies, Volume 89, Pages 35-52.***

**Abstract**:

This paper jointly designs the optimal ship sailing speeds on shipping voyages and the optimal amount of bunker fuel to purchase at each port of a shipping network operated by a container liner shipping company. Bunker prices at these ports are assumed to be correlated random variables. Considering the difficulties in calibrating these prices into specific joint probability distribution in practice, this study merely requires some fundamental descriptive statistics information of these bunker prices, including lower and upper bounds, means and covariances, which can be tangibly estimated from historical data. To solve this problem, a mixed integer programming model is first formulated for deterministic bunker prices to minimize the sum of ship operating cost and bunker consumption cost. This model is subsequently extended to incorporate stochastic bunker prices by developing a series of approximation techniques using the bunker price descriptive statistics information. A numerical example based on real-case price data of a liner shipping network from an international shipping company shows that the proposed model is able to simultaneously control the average bunker purchase cost as well as the risk resulting from the extremely high bunker prices.

11. **Javed Farhan and Ghim Ping Ong (2018), Forecasting seasonal container throughput at international ports using SARIMA models.** ***Maritime Economics & Logistics, Volume 20, Issue 1, Pages 131-148.***

**Abstract**:

Seasonal container throughput forecasts at ports are immensely important to logistics companies, shipping lines, port authorities and shipyards. Such forecasts allow shipping lines and port operators to formulate appropriate short-to-medium strategies in order to maintain competitiveness. Seasonal autoregressive integrated moving average (in short, SARIMA) models can be employed for this purpose to provide reliable seasonal forecasts of container throughput at a given container port. This article explores the use of SARIMA models in forecasting container throughput at several major international container ports, while taking into consideration seasonal variations. First, the SARIMA model development methodology is described. Second, a database consisting of monthly container port traffic data between 1999 and 2007 for international container ports is developed. Short-term container demand forecasting models are then developed for each of the top 20 international container ports for the purpose of monthly container throughput prediction. Through the use of various performance metrics, the effectiveness of the developed SARIMA models for these ports is evaluated. It is found that SARIMA models can produce reliable throughput forecasts at major international ports. Qualitative insights are then drawn, thereby allowing shipping

## Published Technical Papers (with Abstracts)

and port operators to make better tactical and operational decisions.

**12. De Zhao, Wei Wang, Ghim Ping Ong and Yanjie Ji (2018), An association rule based method to integrate metro-public bicycle smart card data for trip chain analysis.** ***Journal of Advanced Transportation, Volume 2018.***

**Abstract**:

Smart card data provide valuable insights and massive samples for enhancing the understanding of transfer behavior between metro and public bicycle. However, smart cards for metro and public bicycle are often issued and managed by independent companies and this results in the same commuter having different identity tags in the metro and public bicycle smart card systems. The primary objective of this study is to develop a data fusion methodology for matching metro and public bicycle smart cards for the same commuter using historical smart card data. A novel method with association rules to match the data derived from the two systems is proposed and validation was performed. The results showed that our proposed method successfully matched 573 pairs of smart cards with an accuracy of 100%. We also validated the association rules method through visualization of individual metro and public bicycle trips. Based on the matched cards, interesting findings of metro-bicycle transfer have been derived, including the spatial pattern of the public bicycle as first/last mile solution as well as the duration of a metro trip chain.

## CMS Research Seminars

### 1. Determination of Minimum Distance to Obstacle Avoidance in the Singapore Strait, by researcher Dr. Lu Zhaoyang (Track leader: Professor Meng Qiang)

**Seminar Abstract:**

In the maritime simulation models of obstacle avoidance, the parameter of the critical contact closest point of approach (CCPA) is defined as the minimum safe distance to avoid an obstacle contact. Although the parameter of CCPA plays a decisive role on the ship maneuvering for obstacle avoidance, it is generally set with an uncalibrated input value in many obstacle avoidance simulation models. This study focuses on the parameter calibration of the critical CCPA by utilizing the AIS data in the Singapore Strait and maneuver simulation experiments. Firstly, an effective mathematical method is proposed to identify ship obstacle avoidance from the big AIS data. Together with several obstacles and the AIS data in Singapore Strait, the average critical CCPA values are identified for different ship classes. Secondly, a series of maneuver simulation experiments on Dalian Maritime University navigational simulators are conducted by professional captains. Based on the experimental data, the simulation-based critical CCPA values are derived. Finally, these calibrated CCPA values from the above two methods are compared and analysed. The comparison result implies that these critical CCPA values, derived from AIS data and maneuver simulators, are matched and confirmed each other's rationality. It also reveals that the average critical CCPA value for each ship class has an increasing trend with the growth of ship length.

### 2. Impact Analysis of Large Ships on Ship Traffic Capacity of the Singapore Strait, by researcher Dr. Kang Liujiang (Track leader: Professor Meng Qiang)

**Seminar Abstract:**

Nowadays, with the increase of large ships, more and more large-sized ships are passing through the Singapore Strait, whose traffic capacity will be inevitably affected. Besides, in view of the randomness of external environment or human factors, the assessment of capacity usually varies. Thus, regarding large ships, how to estimate the mean strait capacity and its variance has become one urgent problem for the strait operation and management. In this seminar, we talk three methods to estimate the risk-based traffic capacity of Singapore: fundamental diagram based capacity estimation method, the Fuji-model based capacity estimation method and simulated based capacity estimation method.

### 3. Impact Analysis of Large Ships on Navigational Risk in the Singapore Strait, by Researcher Mr. Wei Xiaoyang (Track leader: Professor Meng Qiang)

**Seminar Abstract:**

Navigational risk assessment is a major concern for the crew, maritime authorities, shipping industries and researchers. To further enhance the navigational safety, this study proposes a tangible approach to model the navigational risk in the Singapore Strait. The assessment of navigational risk includes two parts, namely i) the estimation of accident probability and ii) the estimation of accident consequences. To determine the risk value of navigational accidents, the probability of occurrence and corresponding consequences should be assessed firstly. Hence risk modeling for navigational accidents presented on this seminar consists two sub-models: i) Occurrence frequency model, and ii) Consequence assessment model. With these methods, we can assess the spatial distribution of navigational risk for certain waters based on a big volume of simulated ship traffic data, and the effectiveness has been illustrated.

## CMS Research Seminars

### 4. Introduction to Discrete-Event Digital Twin - Bridge AI for Enterprise Systems, by invited speaker Dr. Li Haobin (Track Leader: Professor Andrew Lim)

**Seminar Abstract:**

The O2DES.Net is a software framework developed by Dr. Li to facilitate integration between simulation modelling and optimization in different ways towards respective industrial needs. With advanced object-oriented and modularized modelling paradigm, the platform enables precise, flexible and collaborative modelling for a wide range of complex industrial system. Innovative optimization algorithms are included in the package, with the potential to adapt to the parallel computing to boost its performance. With the Centre for Next Generation Logistics (C4NGL), a Warehouse Digital-Twin is recently proposed based on the O2DES.Net framework, aiming to provide timely and affordable solutions to industrial practitioners for warehouse design and operations, in the era of IoT and Industry 4.0.

### 5. A study of possible implementation designs of a Bunker Levy for international shipping, by researcher Ms. Lee Xin Ni (Track Leader: Associate Professor Ng Szu Hui)

**Seminar Abstract:**

Market-based Measures (MBMs), in the form of carbon pricing, have been considered by the international shipping sector to reduce CO2 emissions as existing technical and operational measures are insufficient to achieve emission reductions in line with climate goals. Building upon an earlier proposition that a Bunker Levy is preferred over an Emissions Trading System, this seminar explores the operational details of a Bunker Levy for the sector.

The analysis begins with a literature review on global or sub-global implementation of a tax and the existing IOPC Fund under International Maritime Organisation. MBM implementation in international aviation sector is also studied. Subsequently, key workflow roles, the possible responsible entities and non-workflow design elements are identified and evaluated. Consolidating all the proposals, a few options for operationalising bunker levy are presented, mainly differing in the entity responsible for and the process of funds collection.

### 6. A Review on GHG Emission Reduction Pathway in International Shipping, by researcher Dr. Sou Weng Sut (Track Leader: Associate Professor Ng Szu Hui)

**Seminar Abstract:**

International shipping is the backbone of globalization and predominantly the facilitator of the global trade. The greenhouse gas (GHG) emissions from international shipping will grow rapidly (increasing from 50% to 250% by 2050 as compared to 2012 level. In view of adverse impacts of global warming to the planet, the International Maritime Organization (IMO) has finally reached an agreement on an "initial strategy" for the reduction of CO2 emissions from shipping. The Initial Strategy states that member state delegates have agreed on a target to cut the shipping sector's overall CO2 output by 50 percent by 2050, to begin emissions reductions as soon as possible, and to pursue efforts to phase out carbon emissions entirely. This goal of this Initial Strategy is in line with the Paris Agreement, aiming to keep the global temperature rises this century well below 2°C or if possible to a level of 1.5 □C above pre-industrial level. However, it remains uncertain in how to achieve the proposed target and the associated pathways to reach the targets. This seminar presents a literature review on the various pathways in achieving the CO2 emission target in International Shipping.