Research Highlight 1: Budgeting the Fuel Consumption of a Container Ship Over a Round Voyage via Robust Optimization, By Dr. DU Yuquan (Track Leader: Associate Professor MENG Qiang)

Background

- It is challenging to precisely estimate the bunker fuel consumption of a container ship in a planning horizon, even over a round voyage, since the fuel consumption of a ship in a time unit (say one day) is influenced by many factors, such as its sailing speed, displacement, trim, and weather/sea conditions experienced, in an extremely complicated way
- Sailing speed is the main determinant and influence of sailing speed on fuel consumption rate has recently been well recognized by the maritime studies
- Weather conditions will also significantly affect the fuel consumption rate
- The synergetic influence of sailing speed and weather conditions on fuel consumption of ships is usually ignored

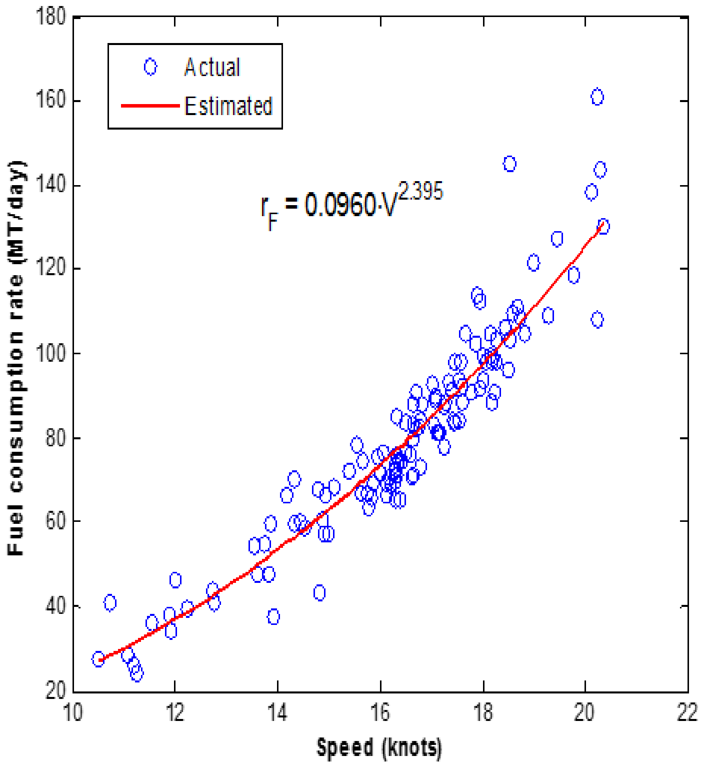

Figure 1. Fuel consumption rate of a 13000-TEU container ship (S1) at different speeds: R2 = 0.9080

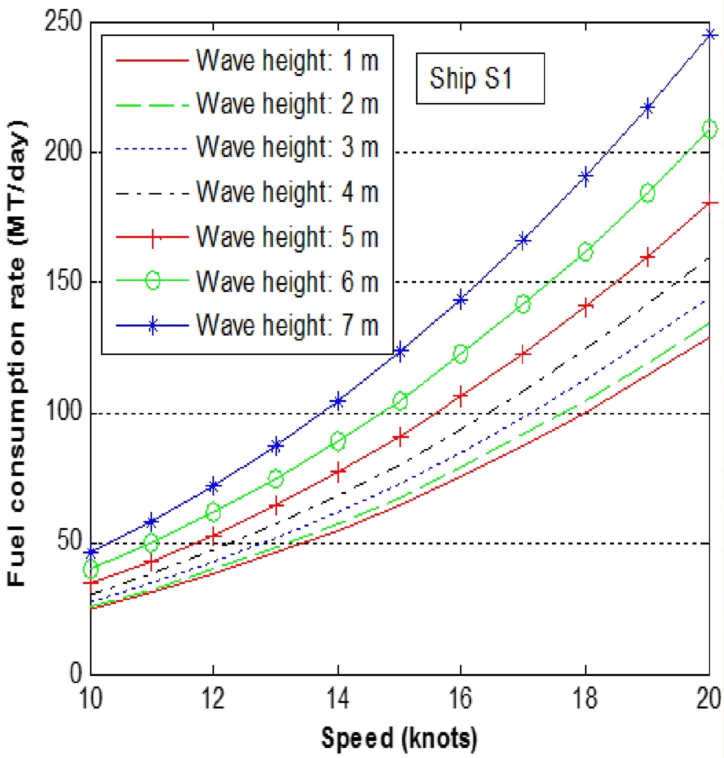

Figure 2. Fuel consumption rate of a 13000-TEU container ship (S1) in bow waves

Objectives and Contributions

Objectives: This study deals with the fuel consumption budget problem of a single container ship over a round voyage by incorporating the coupled influence of sailing speed and weather conditions and the uncertainties in fuel consumption, utilizing the state-of-the-art robust optimization techniques. The robust optimization model and the corresponding solution algorithm can produce different fuel budget values reflecting different conservatism levels of fuel efficiency specialists in container shipping lines.

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Objectives and Contributions

Contributions:

- This study proposes the fuel consumption budget problem of a single container ship over a round voyage, which is a new research topic in maritime studies
- It addresses the synergetic influence of sailing speed and weather conditions on ship fuel consumption which is seldom considered in literature
- This study takes an initiative to extend the applications of robust optimization approaches to liner shipping network analysis

Nominal Mathematical Model without Considering Weather Conditions

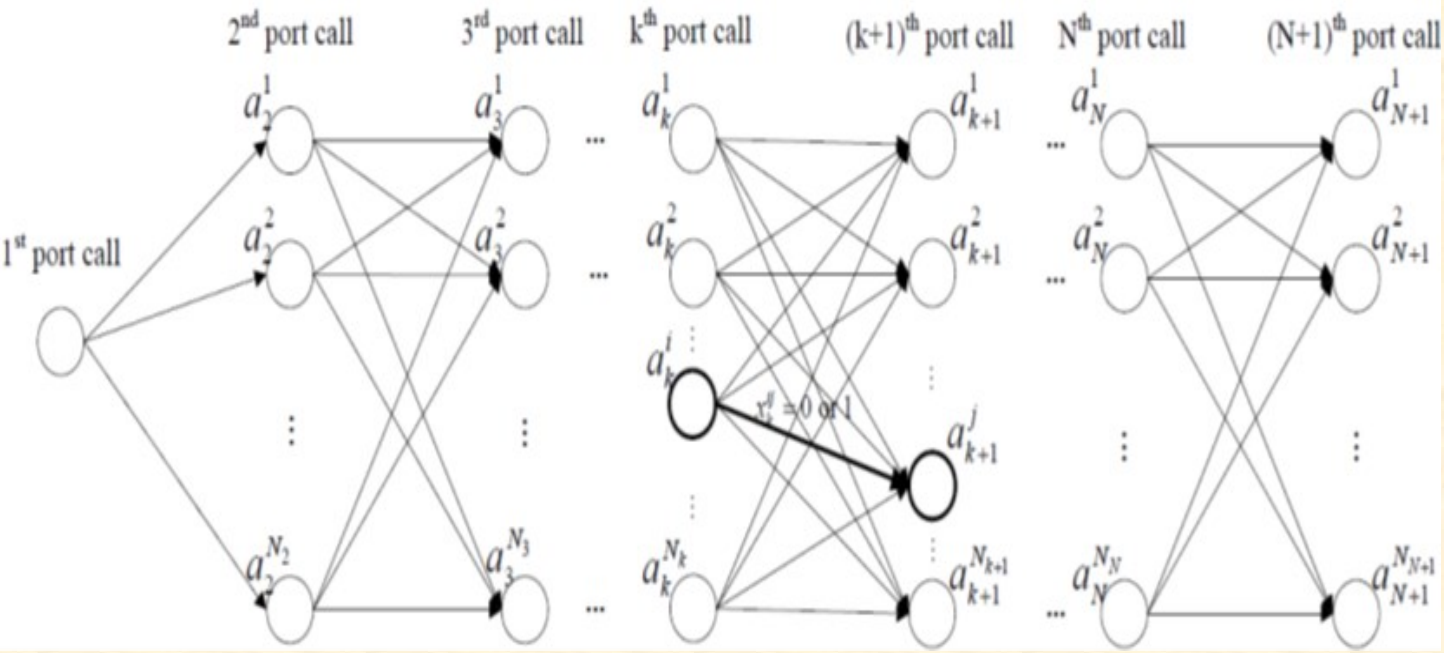

Figure 3. A shortest path model for the nominal fuel budget problem

[NOMINAL]

$$\min \quad F^{NOMINAL} = \sum_{k=1}^{N} \sum_{i=1}^{N_k} \sum_{j=1}^{N_{k+1}} f_k^{ij} \cdot \left(a_{k+1}^j - \left(a_k^i + p_k \right) \right) \cdot x_k^{ij} \quad (1)$$

$$\sum_{i=1}^{N_k} \sum_{j=1}^{N_{k+1}} x_k^{ij} = 1, \quad \forall k = 1,\dots,N \quad (2)$$

$$\sum_{j=1}^{N_{k-1}} x_{k-1}^{ji} = \sum_{j=1}^{N_{k+1}} x_k^{ij}, \quad \forall k = 2,3,\dots N, \quad \forall i = 1,\dots,N_k \quad (3)$$

$$x_k^{ij} \in \{0,1\}, \quad \forall k = 1,2,3,\dots N, \forall i = 1,\dots,N_k, \forall j = 1,\dots,N_{k+1} \quad (4)$$

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Robust Optimization Model with Uncertainty Caused by Weather Conditions

- Due to the adverse influence of bad weather, the real fuel consumption rate of the ship under consideration over the link from the node for to that for , denoted by , is assumed to randomly change in , where is the nominal fuel consumption rate, and reflects the adverse influence of weather conditions.
- Based on the conservatism level of the ship fuel efficiency specialists, it can be assumed that the number of sailing legs on which the fuel consumption rate of this ship perturbates above its nominal value basically does not exceed

  $\Gamma \in \{1, 2, ..., N\}$

[ROBUST1]

$$\min \quad F^{ROBUST} = \sum_{(k,i,j)\in\mathcal{A}} g_k^{ij} \cdot x_k^{ij} + \max_{\{S|S\subseteq\mathcal{A},|S|\leq\Gamma\}} \sum_{(k,i,j)\in S} \Delta_k^{ij} \cdot x_k^{ij} \quad (5)$$

subject to constraints (2)-(4).

Where $\mathcal{A} = \{(k,i,j) | k = 1,...,N; i = 1,...,N_k; j = 1,...,N_{k+1}\}$

$$g_k^{ij} = f_k^{ij}\left(a_{k+1}^j - \left(a_k^i + p_k\right)\right), \quad \Delta_k^{ij} = \delta_k^{ij}\left(a_{k+1}^j - \left(a_k^i + p_k\right)\right), \quad (k,i,j) \in \mathcal{A}$$

Dualizing [ROBUST1] produces the equivalent model [ROBUST2]:

[ROBUST2]

$$\min \quad F^{ROBUST} = \sum_{(k,i,j)\in\mathcal{A}} g_k^{ij} \cdot x_k^{ij} + \Gamma \cdot \lambda + \sum_{(k,i,j)\in\mathcal{A}} \mu_k^{ij} \quad (6)$$

subject to constraints (2)-(4), and

$$\mu_k^{ij} + \lambda \geq \Delta_k^{ij} \cdot x_k^{ij}, \quad (k,i,j) \in \mathcal{A} \qquad \lambda, \mu_k^{ij} \geq 0, \quad (k,i,j) \in \mathcal{A}$$

Solution Method Suggested by Bertsimas and Sim (2003)

Solution Algorithm

Step 1. Sort the indices/arcs in in the decreasing order of its fuel consumption deviation and obtain a new index array O $\Delta_1 \geq \Delta_2 \geq ... \geq \Delta_{|O|}$

Step 2. For $l = 1, 2, ..., |O| + 1$, solve the shortest path problem represented by

$$G^l = \Gamma \cdot \Delta_l + \min\left[\sum_{o=1}^{|O|} g_o \cdot x_o + \sum_{o=1}^{l} (\Delta_o - \Delta_l) \cdot x_o\right]$$

Step 3. Find $l^* = \arg \min_{l=1,...,|O|+1} G^l$, and let the optimal bunker fuel budget value of the ship over a round voyage be G^{l^*} and the robust ship schedule as the shortest path suggested by G^{l^*} .

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Case Study on service LP4 operated by APL

Computational Performance

- Directly solving model [ROBUST2] is time consuming and optimality gaps are considerable in the 300-s time limit (Figure 4)
- The proposed "Solution Algorithm" can solve the problem over the test case to optimality in 15 seconds.

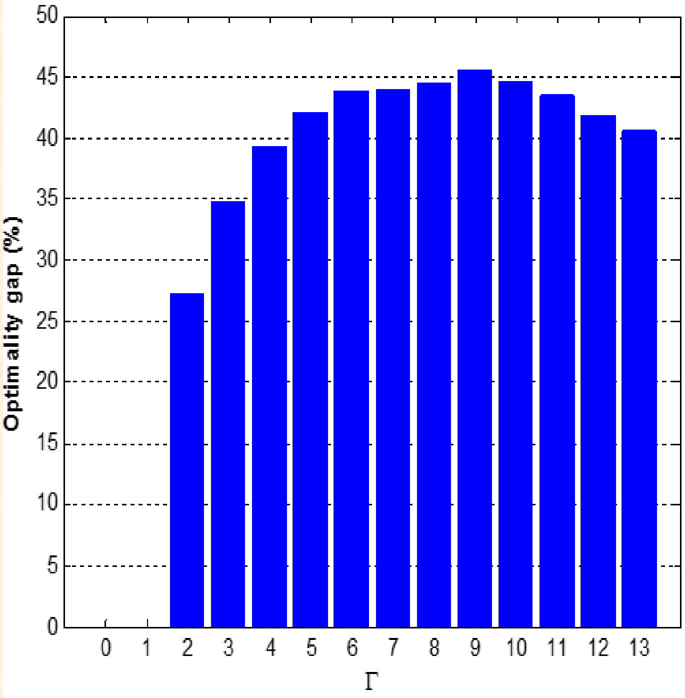

Figure 4. Optimality gaps when CPLEX terminates at the 300-s time limit

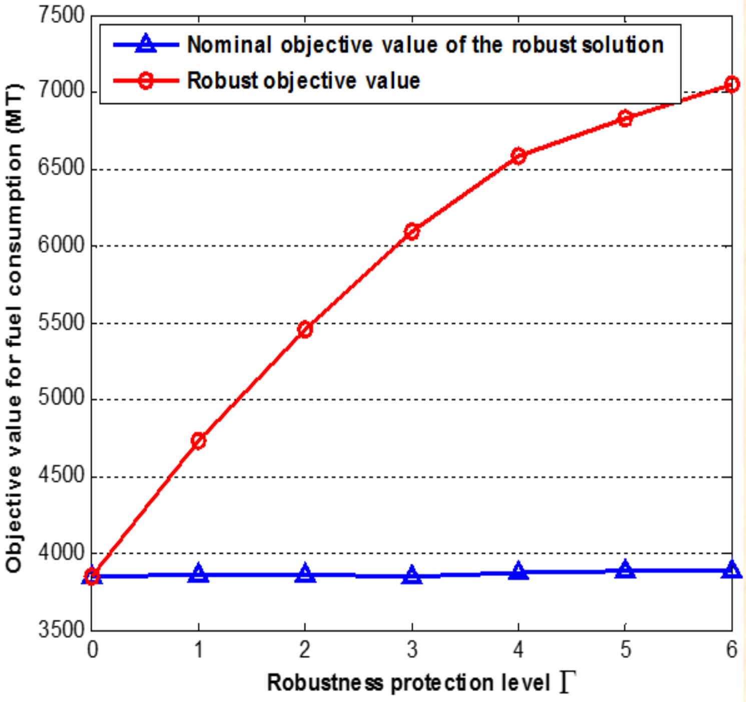

Figure 5. Fuel budget values of ship S1 over a round voyage at different robustness protection levels

Γ	Shipping schedule												
	YAN	YAT	SIN	SUZ	KLV	SOU	HF8	RTM	SUZ	JED	SIN	YAT	NTB
0	5	88	193	533	744	768	833	899	1183	1249	1584	1746	1816
1	5	88	193	552	744	768	833	899	1183	1249	1584	1746	1816
2	5	88	193	552	744	768	833	899	1183	1249	1584	1746	1816
3	5	88	193	533	744	768	833	899	1183	1249	1584	1746	1816
4	5	88	193	533	744	767	827	890	1191	1249	1584	1746	1816
5	4	80	193	533	744	767	827	890	1191	1249	1584	1746	1816
6	4	80	193	533	744	767	827	890	1191	1249	1584	1752	1816

Note: unit: hour; departure time from NTB (first port call) is considered as time zero.

Table 1. Shipping schedules under different robustness protection levels (Γ)

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Case Study on service LP4 operated by APL

Simulation Results

- 100 feasible shipping schedules of service LP4 are randomly generated
- The actual fuel consumption rate of ship S1 over each network link independently perturbs, with probability $\alpha \in \{0.1, 0.2, 0.3, 0.4, 0.5\}$, from its nominal value f_k^{ij} to $f_k^{ij} + \delta_k^{ij}$.
- For each value of , we generate 100 random scenarios and calculate the fuel consumption of ship S1 for each feasible schedule over each random scenario (totally we have 100×100=10000 schedule-scenario combinations for each value of perturbation probability α)

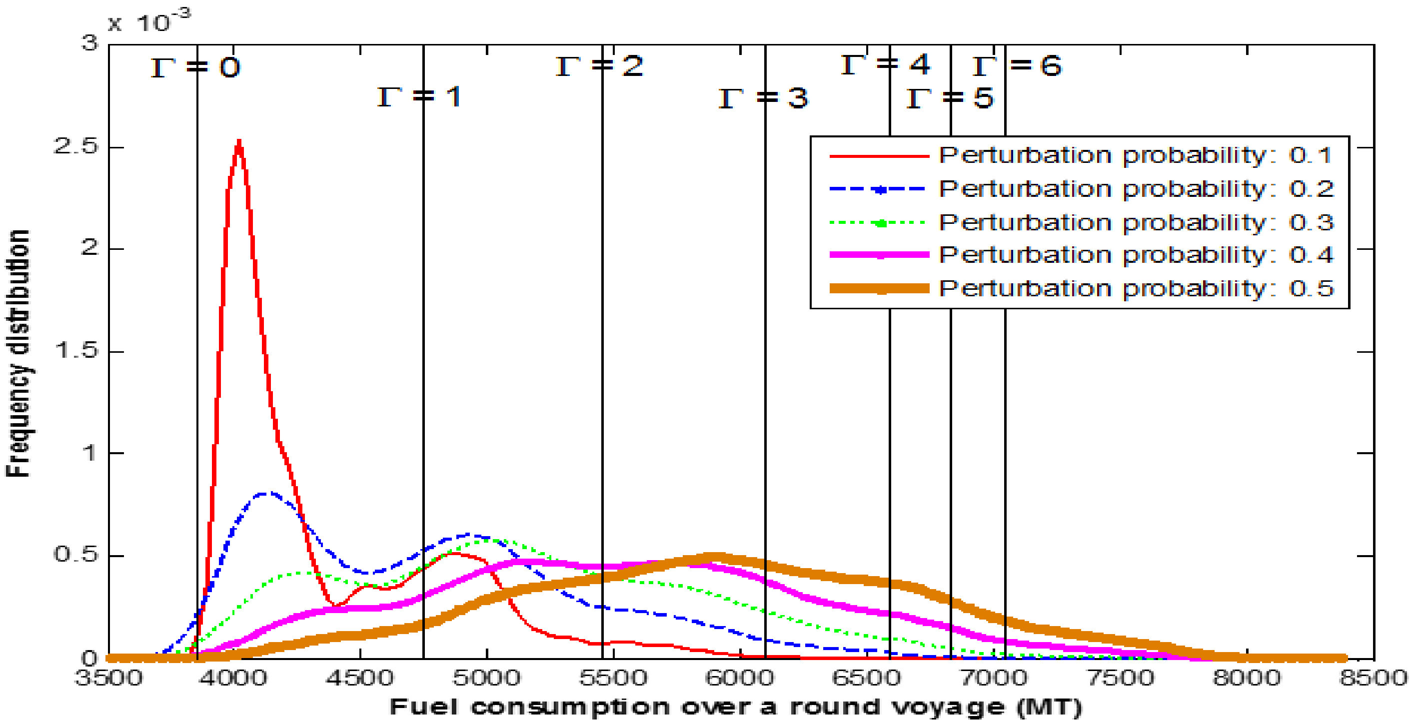

Figure 6. Distributions of fuel consumption of ship S1 over a round voyage with different perturbation probabilities of bunker consumption

Conclusions

- This paper has dealt with the fuel budget problem for a container ship over a single round voyage, inspired by the liner shipping industrial trend in implementing ship fuel efficiency management programs.
- To address the adverse influence of the perturbation of ship fuel consumption rates under severe weather conditions on bunker fuel budget estimation, we employ the state-of-the-art robust optimization techniques developed by Bertsimas and Sim (2003), build a robust optimization model and a highly efficient polynomial-time algorithm.
- The proposed model can work out good fuel budget values at different levels of conservatism under realistic but uncertain situations.

Research Highlight 2: Power Management of Vessel Propulsion System for Fuel Saving and Emissions Mitigation by Dr. Zhao Feiyang (Track Leaders: Associate Professor Tan Woei Wan & Assistant Professor Yang Wenming)

Motivation

To support the objective of studying the fuel consumption and gas emission for a variety of merchant vessel operating scenarios, a mathematical model of the overall ship propulsion plant is developed, and integrated with existing dynamic model of a container ship. Basis of the ship's hydrodynamics model is a force balance equation relating ship resistance, ship dynamics and dynamic ocean environment. The vessel voyage model is capable of representing vessel propulsion behaviour, as well as the dynamic propeller ventilation effect induced by wave irregular motion.

Overall Scheme

In this study, a marine vessel voyage model was built and combined with a two-stoke marine engine that drives a fixed pitch propeller system. Ship-wave interaction is considered from the aspect of thrust loss caused by propeller ventilation induced by wave irregular vibration. An intelligent engine speed governor module that modulates the applied power is employed to reduce thrust loss and improve fuel efficiency.

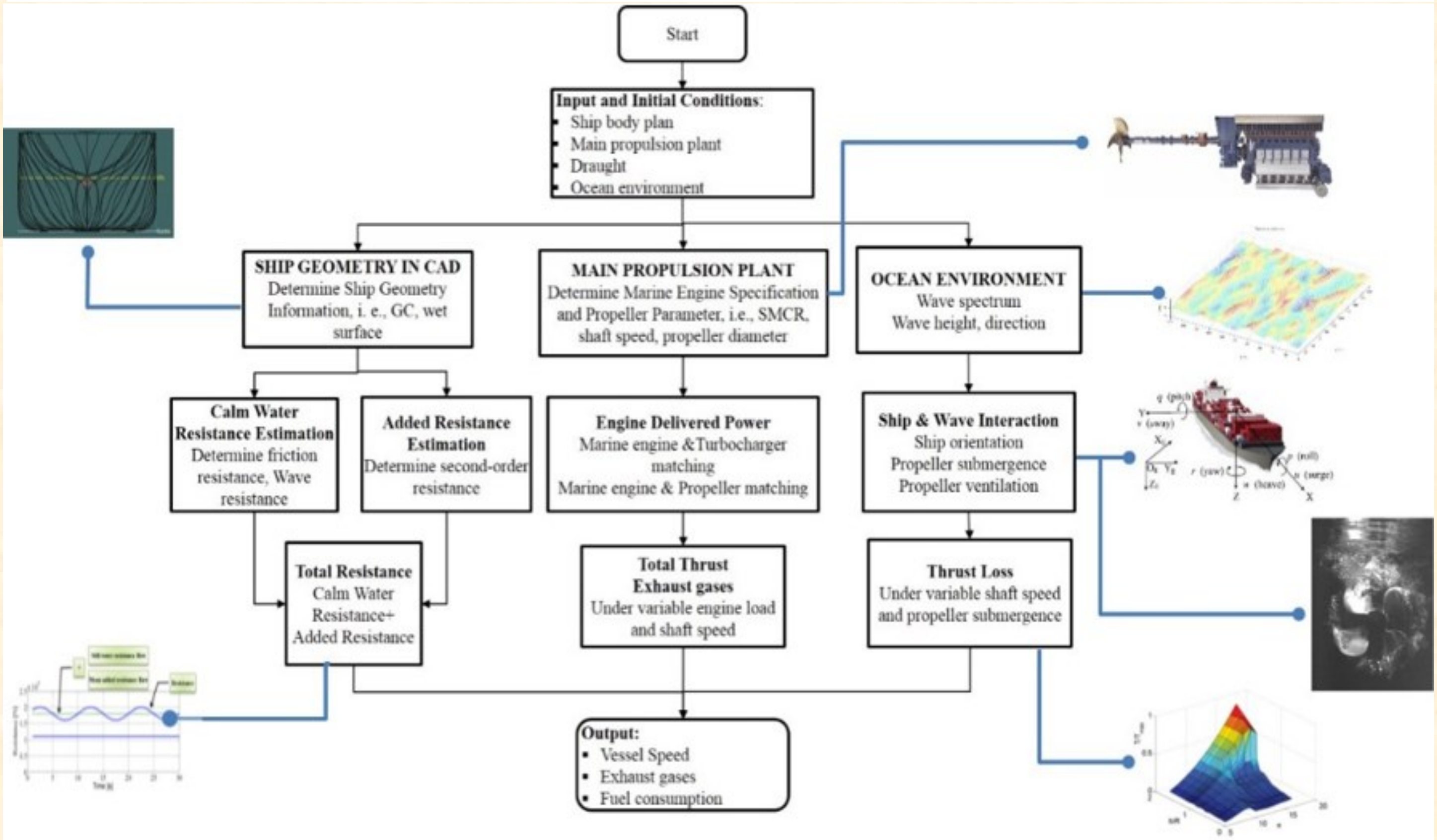

Figure 1: The overall scheme of vessel voyage model

Ship Propulsion Model

Fuel consumption is directly related to marine engine operation conditions. Normally, the propeller of larger container ships are driven by two-stroke main engine that spins with speed lower than 130rpm and four-stroke marine engine is used as auxiliary engine responsible for all onboard power or off-loading equipment when connected with a generator [1].

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In this study, the marine engine is modeled using a cycle mean value approach in conjunction with differential equations for the fast transient power plant performance calculation of the engine crankshaft speed and delivered power. The thermodynamic and flow dynamic process in engine operation are taken into consideration. The main components of the engine are shown in Figure 2.

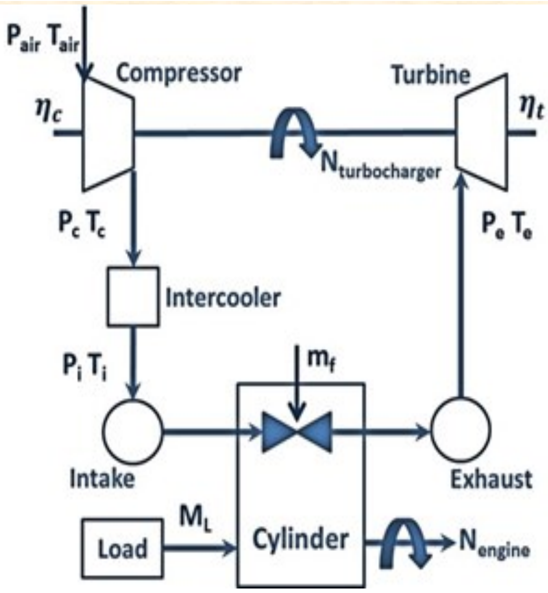

Fig 2. Schematic of engine main components

If there is no gearbox between the two-stroke marine engine and propeller, the propeller rotation speed equals to the engine speed. When the engine delivered power and operation speed are known, the propeller torque Qp and thrust Tp can be calculated using the following dimensionless coefficients:

$$Q_p = K_Q \rho n_p^2 D_p^5 \qquad (1)$$

$$T_p = K_T \rho n_p^2 D_p^4 \qquad (2)$$

Then the propulsion model was integrated into a hydrodynamic vessel model which has six independent coordinates defined to determine the vessel's position and orientation and generated under Marine System Simulator (MSS) Matlab/Simulink platform [2]. Thus, the vessel speed v is given by the motion equation with fluid memory effects:

$$M\dot{\nu} + C_{RB}\nu + C_A\nu_r + \bar{B}\nu_r + G\eta = \tau + \tau_H \qquad (3)$$

When the ship operates in high sea with severe motions, it will cause high amplitude of propeller relative motions. If the propeller operates too close to the water surface, or the submergence of the propeller become small, the localized low pressure created by the blades can draw air under the water and then cause ventilation effects. If the propeller loading is sufficiently high with higher rotation speed, the low pressure on the propeller blades could also create a funnel through which air is drawn from the free surface, thus ventilating the propeller as well. For a heavily loaded propeller, ventilation may lead to an abrupt thrust loss as high as 70-80%, and high thrust loss combined with wave-frequency cyclic variations in propeller loading may cause severe mechanical wear and tear of the propulsion units. Based on the test results from Norwegian University of Science and Technology, as shown in Figure 3, a generic thrust loss model capturing the main characteristics of ventilation may be formulated, with ship position and orientation simulation in MSS module to determine propeller submergence.

The behavior of propulsion system was primarily validated by full seakeeping test data of a 23,400dwt container vessel [3]. Table 1 and 2 list the main parameters of this vessel and marine engine. The measured relations between the engine output power and fuel consumption in calm water conditions are given in Figure 4. The simulation results are generated by the vessel voyage model and assuming that the wave induced effects are negligible. The predictions agree fairly well with the experimental data.

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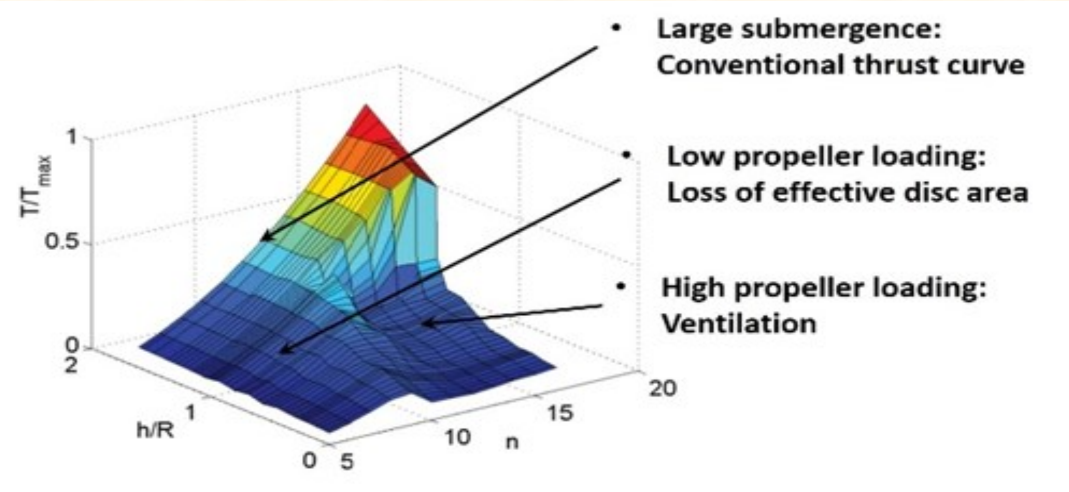

Figure 3. Experimental results showing non-dimensional propeller thrust force versus relative propeller submergence h/R and relative shaft speed n

Length overall	Loa	204.00	m
Length at design waterline	Ldwl	196.70	m
Length between perpendiculars	Lpp	193.10	m
Breadth	B	30.80	m
Draught to design waterline	T	9.00	m
Block coefficient	CB	0.585	

Table 1. Main particulars of the container vessel

Bore	700	mm
Stroke	2360	mm
Number of cylinders	7	
Power at SMCR	22,890	kw
Engine speed at SMCR	108	rpm
BSFC	173	g/kwh
Turbocharger	1 × ABB L190	

Table 3.Specifications of the marine engine

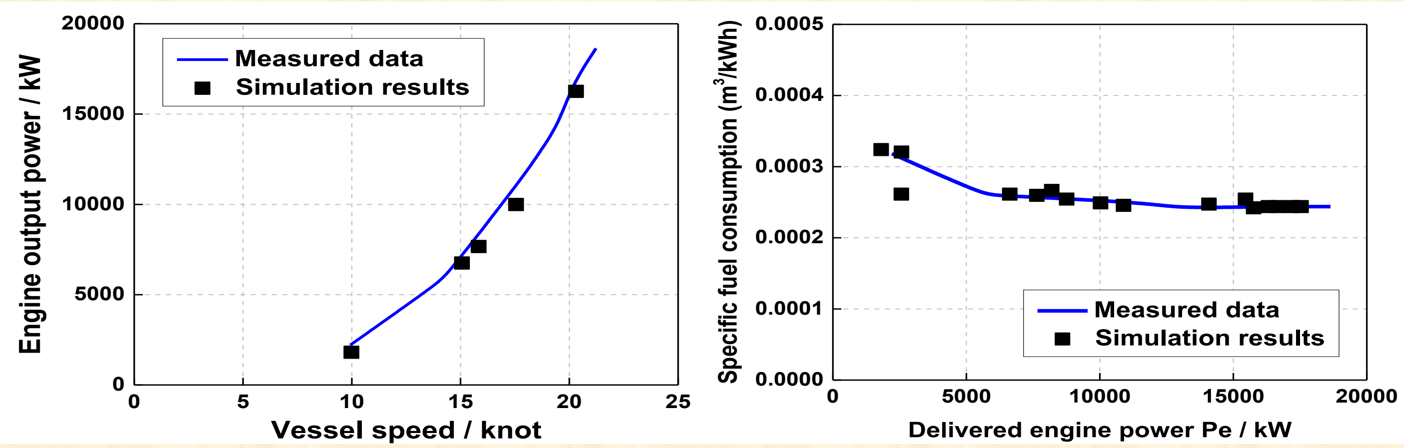

Figure 4. Relationship between measured engine power VS ship speed and fuel consumption VS engine power in calm water condition

Research Highlight 2: Power Management of Vessel Propulsion System for Fuel Saving and Emissions Mitigation by Dr. Zhao Feiyang (Track Leaders: Associate Professor Tan Woei Wan & Assistant Professor Yang Wenming)

Predictions of Vessel Fuel Consumption and Discharged Gas in Real Sea States

Rough sea is the main factor resulting in propeller ventilation phenomenon. When a vessel runs into bad weather, the severe ship motions induced by irregular waves bring the thruster very close to water surface, making propeller susceptible to ventilation and causing huge thrust loss. The ventilation is dynamic and is not probability repeatable from one revolution to the other. Once the negative impact of huge thrust loss is detected, the modulation of operation and sailing strategy would kick in to avoid a deterioration in thrust efficiency.

To imitate rough sea with large waves, the International Towing Tank Conference (ITTC) wave spectrum with significant wave height Hs=5 m and peak frequency ω0 =0.56 rad/s is used in this study. Step modulation of engine speed is utilized to reduce the thrust loss and improve fuel effciency.When the freak wave and ventilation is detected, the engine speed will be triggered to reduce 20%, then keeps at this speed for a certain time to observe the ship behavior. If the thrust loss is still lower than 0.6, the modulation is carried on further until the thrust loss is higher than 0.6.

Figure 5 gives the modulation process of the engine speed according to the thrust loss in a certain sea state. During calm water voyage, the engine speed is accelerated to reach full cruise state at the engine load of 75%, and the propeller is fully submerged with h/R ratio higher than 1.5 and there is no thrust loss observed in this period. When the ship severe motion begins, the propeller submergence level will fluctuat. Sometimes, the propeller may even be very close to water surface. In such circumstances, huge propeller thrust loss is detected and the engine speed is triggered to modulate automatically step by step to minimize the thrust loss. Self-tuning of fuel supply during modulation could be achieved by intelligent engine speed governor module. When the vessel stops sailing in heavy seas, the engine speed is restored to full cruise state. It can be seen (from Figure 6) that after modulation, even for the case of propeller very close to the water surface as the result of high fluctulation of vessel motion, the thurst loss is successfully mitigated.

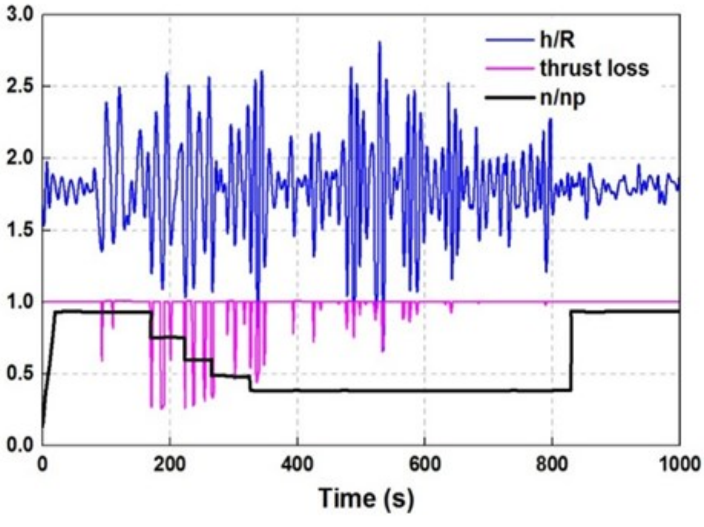

Figure 5. Engine speed modulation process under certain sea state

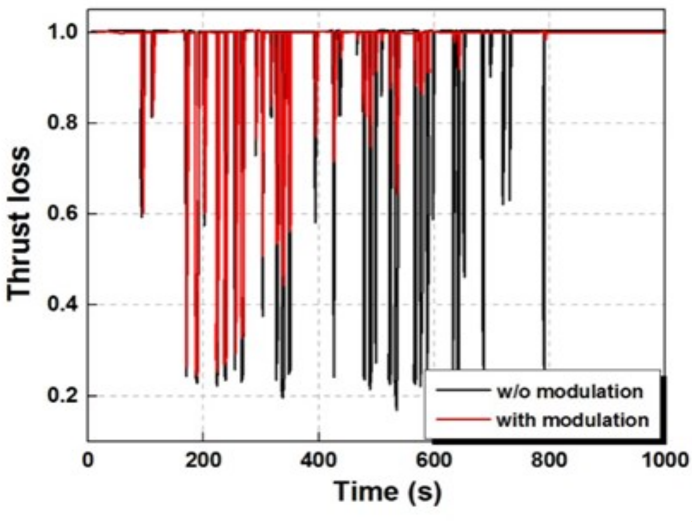

Figure 6. Comparison of thrust loss for the cases with and without modulation

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Predictions of Vessel Fuel Consumption and Discharged Gas in Real Sea States

Power modulation process is not only for propulsion efficiency benefit, but also beneficial for fuel consumption and emissions. When the predicted power delivered by the engine and the ship speed in a rough sea are known, the corresponding fuel consumption and discharged emissions in the specific voyage is attainable. Figure 7 compares the results of fuel consumption and discharged gas emissions under the conditions with or without modulation. For the case of the most adverse weather condition with wave height of 7m, due to the voluntary ship speed reduction by modulation, the sailing distance is shortened by 22.2% at a given period, but almost half fuel is saved. The gas emissions of NOx, CO2 and SOx during this voyage are given based on emission inventory of main engine test [4]:

$$Emissions_{kg} = \int_0^{t_h} (P_{kw} \times F_{\%kw} \times E_{g/kwh} \times \frac{1}{1000}) dt_h \quad (4)$$

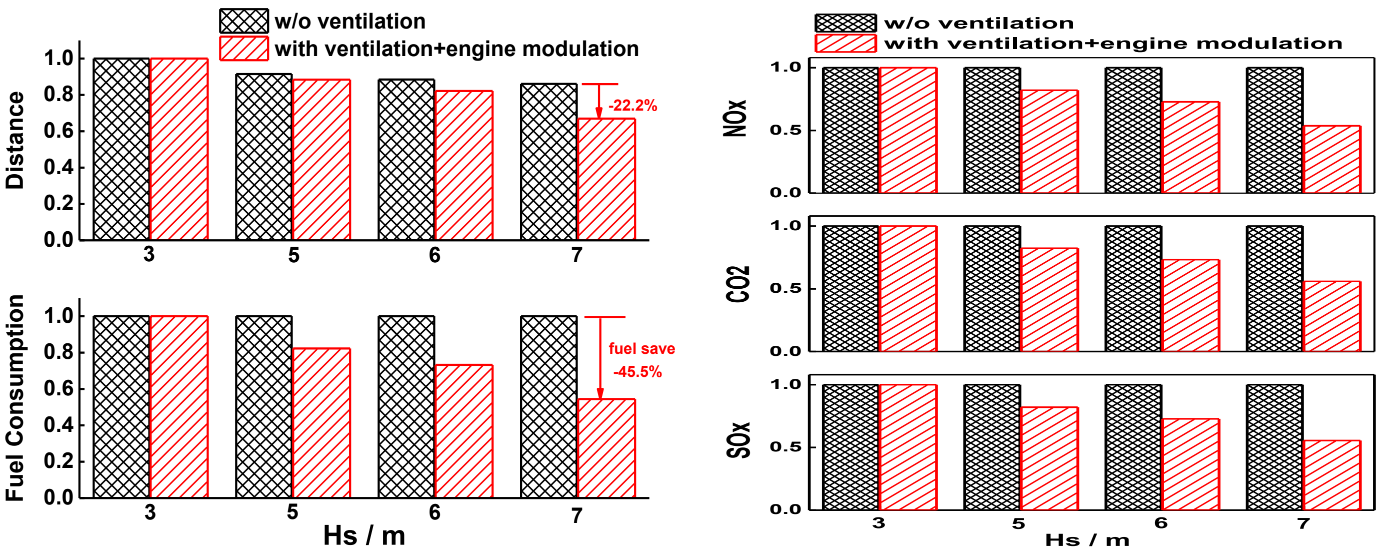

Figure 7. Comparison of fuel consumption and emission gas under different sea states for the cases with and without modulation

Conclusion

Aim to reduce the fuel consumption and gas emission during a container ship operating scenarios, a mathematical model of the overall ship propulsion plant, implemented in the hydrodynamic vessel movement model under the Matlab/Simulink platform was developed. The packed vessel voyage model was capable of representing vessel propulsion behavior, also with dynamic propeller ventilation effect induced by wave irregular motion. According to the thrust loss caused by propeller ventilation, modulation of power management was motivated to avoid deteriorated thrust efficiency. Self-tuning of fuel supply during modulation could be achieved by intelligent engine speed governor module.

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Because the thrust loss combined with wave-frequency cyclic variations in propeller loading may cause huge thrust loss and severe mechanical wear and tear of the propulsion units, step modulation strategy of power management system was motivated to reduce the negative impact. In this study, it managed to save up to 40% thrust loss at a certain sea state. Benefits of fuel saving and pollutant emission mitigation were obvious by power modulation as well, but at the expense of shortened sailing distance at a given time due to voluntary vessel speed reduction.

Acknowledgements

This study is supported by the research project "Analysis of Energy Consumption and Emissions by Shipping Lines" funded by Singapore Maritime Institute.

References

[1] Corbett JJ, Koehler HW. Updated emissions from ocean shipping. Journal of Geophysical Research: Atmospheres 2003; 108:1-15.

[2] Perez T, Smogeli Ø N, Fossen TI, Sørensen AJ. An over view of the marine system simulator (MSS): a Simulink tool box for marine control system. Modelling Identification Control 2006; 27:259–275.

[3] J.M.J. Journée. Review of the 1979 and 1980 Full-Scale Experiments Onboard Containership m.v. Hollandia. DUT-SHL Report 1349, 2003.

[4] JW Miller, Harshit Agrawal, Bill Welch. Measurement of Emissions from the Main Propulsion Engine on a Panamax Class Container Ship. California Air Resources Board final report 2009.

Published Technical Papers (with Abstracts)

1. Jun Yuan, Szu Hui Ng, (2015), Calibration, Validation, and Prediction in Random Simulation Models: Gaussian Process Metamodels and a Bayesian Integrated Solution. ***ACM Transactions on Modeling and Computer Simulation (TOMACS), Volume 25 Issue 3, May 2015, Article No. 18***

Abstract:

Model calibration and validation are important processes in the development of stochastic computer models of real complex systems. This article introduces an integrated approach for model calibration, validation, and prediction based on Gaussian process metamodels and a Bayesian approach. Within this integrated approach, a sequential approach is further proposed for stochastic computer model calibration. Several design criteria for this sequential stage are proposed and studied, including an entropy-based criterion and one based on minimizing prediction error. To further use the data resources to improve the performance of both calibration and prediction, an adaptive procedure that combines these criteria is introduced to balance the resource allocation between the calibration and prediction. The accuracy and efficiency of the proposed sequential calibration approach and the integrated approach are illustrated with several numerical examples.

2. Shuaian Wang, Qiang Meng, (2015), Robust bunker management for liner shipping networks, ***European Journal of Operational Research, Volume 243, Issue 3, 16 June 2015, Pages 789–797***

Abstract:

This paper examines the sailing speed of containerships and refueling of bunker in a liner shipping network while considering that the real speed may deviate from the planned one. It develops a mixed-integer nonlinear optimization model to minimize the total cost consisting of ship cost, bunker cost, and inventory cost, under the worst-case bunker consumption scenario. A close-form expression for the worst-case bunker consumption is derived and three linearization techniques are proposed to transform the nonlinear model to a mixed-integer linear programming formulation. A case study based on the Asia–Europe–Oceania network of a global liner shipping company demonstrates the applicability of the proposed model and interesting managerial insights are obtained.

3. Qiang Meng, Xiuling Hei, Shuaian Wang, Haijun Mao, (2015), Carrying capacity procurement of rail and shipping services for automobile delivery with uncertain demand. ***Transportation Research Part E: Logistics and Transportation Review, Volume 82, October 2015, Pages 38–54***

Abstract:

The determination of the optimal carrying capacity procurement of rail and shipping services in the automobile intermodal network with unique characteristics is essential to save automobile delivery cost. In this research we develop a two-stage stochastic programming model for the tactical-level decision problem arising in the special automobile intermodal network. Furthermore, we improve the sample average approximation algorithmic procedure to solve the model. We apply the model and solution method to a case study associated with the Shanghai Automobile Industry Corporation. We believe that this study deals with an emerging new research topic with practical significance for the automobile industry.

Published Technical Papers (with Abstracts)

4. Yuquan Du, Qiang Meng, Yadong Wang, (2015), Budgeting Fuel Consumption of Container Ship over Round-Trip Voyage Through Robust Optimization. ***Transportation Research Record: Journal of the Transportation Research Board, August 2015, Issue 2477, Pages 68-75***

Abstract:

A proposed practical fuel budget problem aims to determine a group of bunker fuel budget values for a liner container ship over a round-trip voyage under uncertainties caused by severe weather conditions. According to research collaboration with a global container shipping line in Singapore, the proposed problem holds a kernel position in the ship fuel efficiency management programs advocated by container shipping lines because of the downward pressure of soaring bunker prices. The synergetic influence of sailing speed and weather conditions on ship fuel consumption rate was considered when the bunker fuel budget of a ship over a round-trip voyage was estimated. To address the adverse random perturbation of fuel consumption rate under severe weather conditions, state-of-the-art robust optimization techniques were employed, and a robust optimization model for the fuel budget problem was developed. The developed model can be dualized into a mixed-integer linear programming model that may be solved by commercial optimization solvers. However, algorithmic findings in the field of robust optimization provided a polynomial time solution algorithm, and it was retrofitted to accommodate the proposed ship fuel budget problem. The case study of an Asia–Europe service demonstrates the computational performance of the proposed solution algorithm and the competence of the proposed robust optimization model to produce fuel budget values at different levels of conservatism possessed by the fuel efficiency specialists in container shipping lines.

5. Sugoutam Ghosh, Loo Hay Lee, Szu Hui Ng, (2015), Bunkering decisions for a shipping liner in an uncertain environment with service contract. ***European Journal of Operational Research, Volume 244, Issue 3, 1 August 2015, Pages 792–802***

Abstract:

As bunker fuel cost constitutes a major portion of the shipping liners' operating cost, it is imperative for them to minimize the bunkering cost to remain competitive. Service contract with a fuel supplier is a strategy they venture on to reduce this cost. Typically, liner operators enter into a contract with fuel suppliers where the contract is specified by a fixed fuel price and amount, to mitigate the fluctuating spot prices and uncertain fuel consumption between the ports. In this paper, we study such bunkering service contracts with known parameters and determine the liner's optimal bunkering strategy. We propose to use bunker up to level policy for refueling, where the up to level is dynamic based on the observed spot price and determine the bunkering decisions (where to bunker and how much to bunker) at the ports. A dynamic programming model is formulated to minimize the total bunkering cost. Due to the inherent complexity in determining the gradient of the cost-to-go function, we estimate it by Monte Carlo simulation. Numerical experiments suggest that all the contract parameters must be considered together in determination of the optimal bunkering strategy. Contracting an amount lesser than the average consumption for the entire voyage, at a contract price lesser than the average spot price is found to be beneficial. The insights derived from this study can be helpful in designing these types of service contracts.

Conference Papers (with Abstracts)

1. Qiang Meng, Yiru Zhang, Min Xu, (2015), Viability Of Transarctic Shipping Routes: An Overview. ***Global Integration of Economies and Connectivity Development, August 31-September 1, 2015, Downtown Campus, Soochow University, Taipei***

Abstract:

The Arctic ice has been observed to be decreasing in terms of extent and thickness in all seasons due to global warming. The latest record lows in Arctic sea ice extent, together with ice model projections of additional ice reductions in the future, have fuelled speculations of new transarctic shipping routes to be operational soon. While the media vigorously propagates the great potentials of these shipping routes, researchers have accessed the feasibility and impact of opening of transarctic shipping routes from various perspectives, including ice condition, regulatory encounters, economic viability and environmental challenges; and diverse and some polarized conclusions have emerged. One important consensus is that it is only a matter of time before new sea lanes will be viable; nonetheless, the challenges faced by the shipping industry are still overwhelming. This paper aims to critically review the studies that examine the necessary conditions and requirements that make the transarctic shipping routes sufficiently viable. We start from shipping operators' perspective, and classify the studies into two aspects: navigation conditions and commercial features. These studies are analyzed and compared in depth. Finally, possible future research directions are put forward.

2. R. Weng, Pedrielli, G., Lee, L. H., and Ng, S. H. (2015). A Dynamic Programming Approach for the Bunkering with Contract Problem. ***The 2015 International Conference on Logistics and Maritime Studies, August 27-29, 2015, Hong Kong***

Abstract:

Bunker fuel constitutes more than 75% of the total operational costs for a liner shipping company. In order to provide an economically efficient service, bunker cost minimization via refueling planning (i.e., where and how much fuel to purchase) and voyage speed control have been extensively investigated in the scientific literature as well as in the industrial practice. A key aspect increasing the complexity of these problems is the bunker fuel price volatility among different ports as well as in time. In fact, to hedge against such price features, bunker contracts are widely adopted as a means to guarantee liner companies the delivery of fuel under controlled price conditions. Nevertheless, in light of such hedging strategies, the aforementioned control and planning activities require further improvement by designing dynamic bunkering plans and speed control which consider stochastic prices and contracts, i.e., the dynamic bunkering with contract problem (DBCP) needs to be addressed. In this paper, we propose, for the first time, a stochastic dynamic programming based approach to solve the DBCP, i.e., given a single contract has been established for a single vessel, we provide a policy that optimizes the voyage speed and chooses where to bunker as well as the amount of fuel to buy on market or/and contract terms, when the bunker prices follow some predefined stochastic process.

Conference Papers (with Abstracts)

3. Pedrielli, G., R. Weng, Huang, W., Lee, L. H., and Chew, E. P. (2015). Models for Bunkering Price Forecast. ***The 2015 International Conference on Logistics and Maritime Studies, August 27-29, 2015, Hong Kong***

Abstract:

As the shipping companies have started focusing on cost reduction, bunkering problems have received remarkable attention. To achieve effective bunkering strategies, bunker price fluctuation between ports and in time need to be considered. In this manuscript, we are specifically concerned with the operational level bunkering decision making. In this context, models for daily bunker prices are compared in terms of quality of fit against a data set of bunker price for several ports worldwide. Specifically, a multivariate non-stationary model (MNSM) and a mean reverting model (MRM) are first considered. Based on the fitting results, we finally propose a modified joint model (MJM), which builds upon a joint model proposed in the literature. The developed MJM fits well to the current data set particularly due to the seasonal component. We test the forecast quality with satisfactory results.

4. Pedrielli, G., Chee, J. W., Lee, L. H., and Chew, E. P. (2015). A New Revenue-Based Empty Repositioning. ***The 2015 International Conference on Logistics and Maritime Studies, August 27-29, 2015, Hong Kong***

Abstract:

Ocean Liners face the daily issue of efficiently managing the flow of containers and their distribution along the ports of call in their service in order to meet the demand at each port while maintaining the operational costs to a minimum level. Trade imbalances make the problem hard and the effective management of the empty containers becomes strategic to the company. In the industrial practice, as well as in most of the literature on empty container repositioning, the demand is considered given. However, the key to make empty repositioning effective is to explicitly consider the demand and the deriving revenues. We refer to this new perspective as Revenue Empty Container Repositioning (RECR) and we propose, for the first time, a two-stage integrated approach which derives pricing decisions to influence demand at the different locations in the liner network while considering the network operations as in the traditional cost-based ECR problem.

CMS Research Seminars

1. RECR: Revenue Based Repositioning Of Empty Containers, by Researcher Dr. Pedrielli Giulia (Track Leader: Associate Prof Lee Loo Hay)

Seminar Abstract:

Ocean Liners face the daily issue of efficiently managing the flow of containers and their distribution along the ports of call in their service in order to meet the demand at each port while maintaining the operational costs to a minimum level. Trade imbalances make the problem hard and the effective management of the empty containers becomes strategic to the company. In the industrial practice as well as in most of the literature on empty container repositioning, the demand is considered given. However, the key to make empty repositioning effective is to explicitly consider the demand and the deriving revenues. We refer to this new perspective as Revenue Empty Container Repositioning (RECR) and we propose, for the first time, a two-stage integrated approach which derives pricing decisions to influence demand at the different locations in the liner network while considering the network operations as in the more traditional ECR problem.

2. Active Control of Marine Structure-A Case Study, by Researcher Dr. Yang Jiasheng (Track Leader: Associate Prof Tan Woei Wan)

Seminar Abstract:

Marine structures are various kinds of vehicles and facilities, which are assigned and installed in the ocean for transport, energy, food as well as mineral resources. In order to improve the properties of marine structures in the complicated ocean environment, their stability should be carefully considered in the design and operation of structures. Due to natural limitations of experiment, theoretical analysis with numerical simulation has been widely used in this field. In this presentation, we investigate a stabilization problem of the simplified fixed platform model under ocean wave. A control algorithm is proposed to stabilize the horizontal vibration of the structure. Numerical simulations are used to illustrate the effectiveness of the proposed methods. It is theoretically proved that the proposed methods could significantly improve the safety and comfort of the structure in the industrial application.

3. Spatial Organization Mechanism of Port Backup Area: A Case Study of Shanghai, by Researcher Dr. Fu Haiwei (Track Leader: Associate Prof Lee Loo Hay)

Seminar Abstract:

Since the 1990s, the port and shipping backup service gradually replaced the traditional sea transportation to become the key factor of port systems, which upgrades the port to be the global supply chain center. According to this new port geography phenomenon, this research aims at port backup area in Shanghai, which could provide the evolutionary model in order to distinguish the features during different evolutionary stages. This research also analyzed the spatial pattern of port logistics enterprises, the interactive effect between port backup area and city, and the comprehensive transportation costs in port backup area.

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4. Ship Traffic Simulation Model for Mixed-type Vessels in Port Waters, by Researcher Dr. Zhang Liye (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

The water area for a large port such as Singapore port has high ship traffic density because of the continuously increasing international seaborne and behaviors of ships sailing in in the port waters exhibit high diversity. Therefore, it is important for the maritime authorities (e.g. Maritime and Port Authority of Singapore) to capture a picture of ship movements in port waters in the near future. This presentation will introduce a ship traffic simulation model for mixed-type vessels in port waters for the purpose of safety evaluation. The simulation approach is based on a data-driven simulation model, and takes interactions between ships into consideration by expert judgment from experienced personnel and AIS data. Discrete event models are applied to generate vessels with different categories and velocities from different traffic zones in the port water. To evaluate the usability of this simulation approach for safety evaluation, the simulation approach will be further verified by comparing both of the actual travel speed and SSD(Ship Safety Distance) distribution. In this presentation, some preliminary results will be shown.

5. Evaluating the Solution Performance of IP And CP for Berth Allocation with Time-Varying Water Depth, By Dr. Du Yuquan (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

This study considers the berth allocation problem (BAP) with time-varying water depth at a tidal river port. Both integer programming (IP) and constraint programming (CP) models are developed. Numerical experiments find that CP tends to be superior to IP when the feasible domain is small (e.g. dynamic vessel arrivals), when the restriction of the objective towards decision variables is loose (e.g. makespan, departure delay), or when the size of IP models is too large due to fine time resolution. Meanwhile, CP’s incapability of proving optimality can be compensated by post-optimization with IP, by using a simple CP/IP hybrid procedure.

6. Power Management of Vessel Propulsion System for Fuel Saving and Emissions Mitigation, By Dr. Zhao Feiyang (Track Leader: Assistant Prof Yang Wenming)

Seminar Abstract:

To meet the more and more stringent gas emissions legislation in marine industry achieving green shipping, the ship operational behavior in actual sailing condition is one of the major concerns for designers and ship owners. In this study, the assessment of fuel consumption and pollutant gas emissions during a container ship operating scenarios was carried out by a hydrodynamic vessel movement model capable of representing the vessel propulsion behavior. The marine engine equipped with turbocharger as well as shafting system and fixed pitch propeller was included in vessel propulsion model by separated sub models connecting the required variables to each other. The propulsion system performance in calm water was well validated by a container ship seakeeping test published in 2003. When sailing encounters heavy weather, the severe ship motion induced by irregular waves bring the thruster very close to water surface, making propeller susceptible to ventilation and causing huge thrust loss. Step modulation strategy of power management system has been employed to save thrust loss and improve fuel efficiency in this study. It was found that there would be an up to 45% fuel saving due to modulation in rough sea.

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7. ESCAPE: An Elastic Data Stream Computational and Analytical Processing Engine, by Researcher Mr. Shi Lei (Track Leader: Associate Prof Bressan Stephane)

Seminar Abstract:

In the era of "Big Data", it is of great importance to retrieve insightful information from huge volumes of data efficiently. However, existing widely adopted large-scale data processing platforms (such as MapReduce) are originally designed for batch processing, making them difficult to support user interactions nor real-time analytical tasks. In this work, we study elastic and efficient data stream processing techniques. By identifying four required features for supporting elasticity in online processing, we develop ESCAPE, a platform supporting efficient and real-time data stream processing. Experimental results validate the efficiency of ESCAPE by comparing with existing batch-based and stream processing systems.

8. The Heuristic Algorithm of Stacking Layer for the Three-Dimensional Packing of Fixed-Size Cargoes, By Researcher Dr. Liu Wangsheng (Track Leader: Associate Prof Lee Loo Hay)

Seminar Abstract:

According to the actual operation of working people, a heuristic algorithm of stacking layer that meets the requirements of stability and convenience for load-and-unload was proposed. Firstly, choose the stacking direction according to the position of the compartment door. Secondly, optimize the combination of length, width and height along the stacking direction to minimize the remaining space. Finally, optimize each layer's layout. In each layer's layout, adopt long-short edge combination mode for each edge. Considering the flatness and stability of loading and unloading, the number of long-short edge is related. Experiment results show that the algorithm can maintain the requirements of stability and convenience of loading and unloading, and also has nice space utilization.

9. The briefing on IMO session MEPC68, By Capt. Tey Yoh Huat

Seminar Abstract:

A Brief Introduction on IMO session MEPC68.

10. Current Ship Traffic Analysis at Northern Sea Route, By Researcher Ms. Zhang Yiru (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

While the media vigorously propagates historic NSR transits and researchers demonstrate viability of the NSR, the current usage by the shipping industry has been neglected thus far. This study aims to analyze the current ship traffic characteristics at NSR. The ship traffic data provided by Russia and the port call data obtained through a commercial provider are examined. Transit shipping along the NSR was performed by 2, 4, 41, 46, 71 and 53 ships respectively in 2009-2014 in the summers. Trade volumes remained unstable over the years. The results show that navigation season lasts for 5 months at NSR, and ice classes of Arc4 and Arc5 are used extensively. Despite Arctic nations, China, Republic of Korea and Japan are active participants in the transit activities. Thus far, oil-and-gas transportation dominates the transits and most activities are destinational or domestic. However, without actual trajectories of activities, it remains difficult to determine the vessel speed on the NSR. The paper provides real statistics that can add value to the viability analysis. It identifies key players of the transits, exhibits trade pattern at NSR.

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11. Hydroelastic Response of Floating Beam Structure, by Researcher Dr. Yang Jiasheng (Track Leader: Associate Prof Tan Woei Wan)

Seminar Abstract:

Nowadays more and more ultra-large vessels are in service for cargo transportation to reduce operating costs. Ultra-large vessels are relatively more flexible and their structural natural frequencies can fall into the range of the encounter frequencies in an ordinary sea spectrum. The hydroelastic response of ultra-large vessels becomes an important issue to ensure ship safety. In this presentation, we use a floating beam to simulate ultra-large ship flexible structure in irregular waves. The procedure of model development is introduced. Then, parametric studies are given to increase our knowledge to understand the hydroelasticity of ultra-large vessel.

12. A Solution Framework for Ship Schedule Recovery Integrating Data Science and Optimization Techniques, By Dr. Du Yuquan (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

This study proposes a solution framework for ship schedule recovery integrating data science and optimization techniques. The framework consists of two modules: data model and optimization model. The data model is an ANN (artificial neural network) model for ship fuel efficiency, which quantitatively measures the bunker fuel consumption of the ship at different sailing speeds, with different load and weather/sea conditions. The optimization model is a time-space network model which could be employed to design operational sailing speeds over consecutive waypoints of a voyage. The calculation of link cost of this time-space network model takes advantage of the ANN data model. Actually, this framework applies to both ship schedule recovery and regular schedule design. We also verified its performance in bunker fuel savings over a 9000-TEU containership. This study is supported by a SMI project ("Analysis of Energy Consumption and Emissions by Shipping Lines") and a NOLF project ("Big Shipping Log Data Driven Ship Fuel Efficiency Analysis and Management: Model Building & Software Development").

13. Evidence-based Ship Accident Consequence Analysis using Heterogeneous-source Accident Reports, By Researcher Dr. Zhang Liye (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

Shipping movements are operated in more and more complex environment due to increasing maritime traffic demand. Fatal ship accidents are nightmares for seafarers. A wide range of methods have been introduced for ship accident consequence analysis. However, almost all existing academic studies focus on experts' understanding in related the consequence analysis, but overlook the potential valuable evidence in real ship accident cases. Actually, a large amount of ship accident reports with detailed accident information are available online and freely accessible. In this paper, we present a systemic framework for the evidence-based ship accident analysis using real ship accident reports and show some knowledge extracted from the real accident records. The first task of the proposed framework is to review ship accident reports and extract related accident information. Different from the previous studies, the accident information of both during-accident stage and post-accident stage are considered and examined. To further show the fulfillment of this task, 477 accident reports are reviewed. The next task is to explore ship accident frequency according to various accident types and accident consequences. The last framework component aims to investigate the relationship between contributory factors and accident consequences.

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Specifically, a series of statistic examinations including nonparametric statistics of Kendall's tau coefficient analysis, Cramér's V coefficient analysis and Kruskal-Wallis test are carried out to figure out the relationship. Our statistical analysis indicates that the significance of contributory factors exhibits distinguished diversity according to ship accident and consequence types, for example, ship speed remarkably contributes to human injury and fatality in ship collisions, but not significantly in ship groundings. The results are beneficial to facilitate the ship risk mitigation and, to validate and advance the existing accident consequence analysis models.

14. Research on Regional Agglomeration Efficiency of Shipbuilding Industry in China, by Researcher Dr. Fu Haiwei (Track Leader: Associate Prof Lee Loo Hay)

Seminar Abstract:

The agglomeration efficiency of shipbuilding industry can reflect the industrial agglomeration effect of different areas. The paper uses location quotient method to calculate the degrees of labor and enterprise agglomeration of shipbuilding industry in different provinces in order to distinguish the situation of regional agglomeration of shipbuilding industry in China. The data envelopment analysis is then used to evaluate the efficiency of profit, output and export in provinces with high degree of agglomeration respectively. This paper also gives related suggestions for the development of shipbuilding industry.

15. Optimal Hedging for Liner Bunker Procurement, By Researcher Mr. Wang Yadong (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

This study proposes the optimal bunker procurement risk hedging problem for a liner shipping company to plan bunker procurement strategy against bunker price fluctuation by means of the swap contract. A tangible two-step approach, including Step 1: historical data based prediction for movements of the swap contract and spot market prices of bunker by the multivariate GARCH time series model and Step 2: optimal hedging strategy determination at a particular month by the scenario tree based stochastic programming model, is developed for solving the proposed problem. In the step 2, a novel scenario tree construction method is first developed to construct the price scenario tree by a revised moment matching method and vector variable decomposition. Based on the constructed scenario tree, the bunker procurement cost mean variance minimization model is subsequently formulated and transformed to the approximate convex quadratic programming, which can be efficiently solved by interior point algorithm in polynomial time. A case study is finally conducted to assess the developed approach.

16. Discrete Choice Models- Existing Model Structures, By Researcher Ms. Zhang Yiru (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

The viability of transarctic shipping routes can be understood from navigation and commercial perspectives. The impact on the port of Singapore can be analyzed by quantifying the shift in shipping market share from traditional shipping routes to transarctic routes. The changes in shipping market share can be estimated by using discrete choice models such as the multinomial logit (MNL), nested logit (NL) and mixed logit (ML) models. We will briefly go through the commonly used discrete choice models to have a basic understanding of the characteristics of various structures.

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