NUS National University of Singapore
Centre for Maritime Studies

CMS RESEARCH UPDATES MARCH 2015

November 2014 – February 2015

Research Highlight 1: Ship Resistance Prediction for Ship Routing Plan, By Dr. Yang Jiasheng (Track Leader: Associate Prof. Tan Woei Wan)

Problem Statement

Ship routing is a procedure to determine an optimal route based on the weather forecasts, the characteristics of a specific ship, and sea states for a particular voyage, fuel consumptions and gas emissions and so on. The optimal route can be regarded as the voyage route that is safest and comfortable for the crew, maximum energy efficiency, minimum time consumption, or a combination of the above factors. The reliability of the optimal route derived from the ship routing system is mainly based on the estimation accuracy of ship resistance to further predict fuel consumption in uncertain ocean environments.

Objectives

- Exploit numerical methods to estimate ship resistance in uncertain ocean environments.
- Numerical simulation is calibrated and validated and applied to predict ship resistance for S-204 container ship voyage [1] in uncertain ocean environments.
- The effect of ship speed, wave pattern and displacement to ship resistance is studied.

Modeling Approach

Seakeeping characteristics of the ship include six degrees of freedom motion, as shown in Figure 1.

The fluid is described to be inviscid, homogeneous and impressible, and the motion is described to be irrotational. The total velocity potential of the fluid can be expressed as $\Phi(t) = \Phi_I(t) + \Phi_S(t)$

where $\Phi_I(x,t)$ is the incident wave potential and $\Phi_S(x,t)$ is the scattering wave potential.

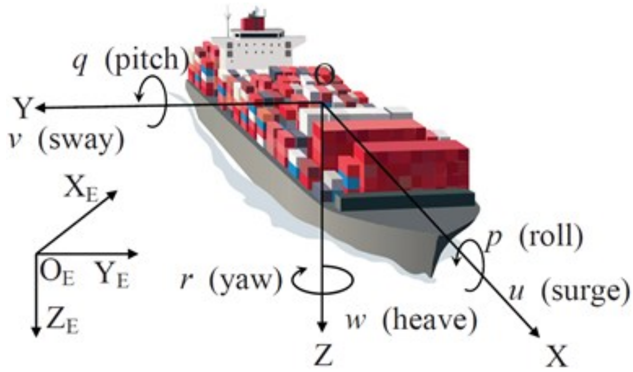

Figure 1. The schematic diagram of ship motion in the wave

The incident wave potential on the ship wet surface has the following form according to the linear wave theory:

$$\Phi_I(x,t) = \frac{\zeta_a g}{w} e^{-kd} \sin\left(k_w x - wt\right)$$

where k_w is the wave number for infinite water depth which satisfies the linear wave dispersion relationship $k_w = w/\sqrt{g}$; ζ_a is the amplitude of the wave and can be obtained by $\zeta_a = \sqrt{S_{\text{JONSWAP}}(w)\delta w}$

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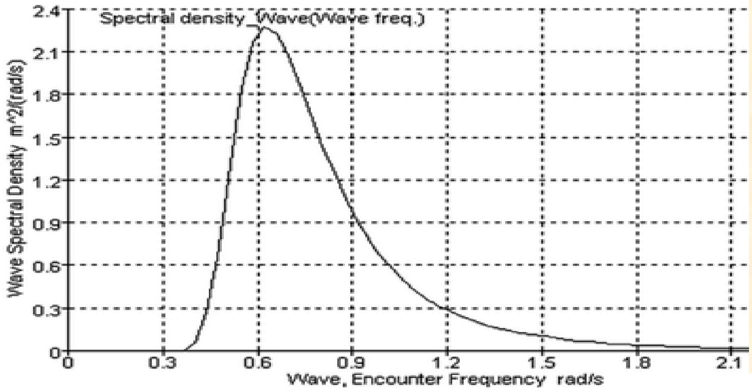
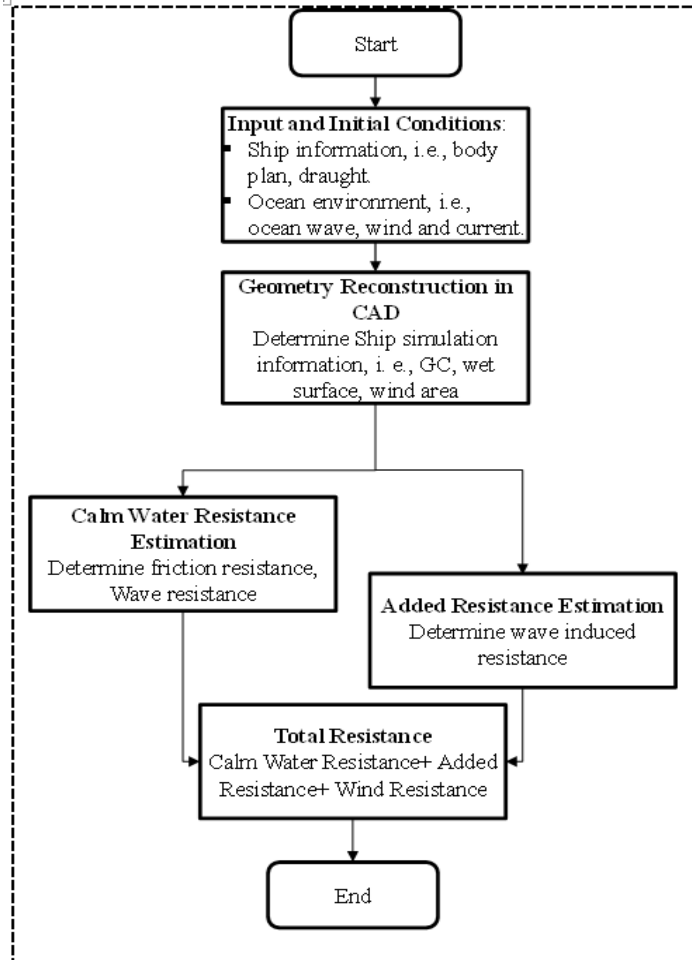
Modeling Approach

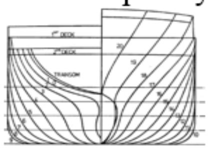
where δw denotes a small interval around the wave frequency w. $S_{\text{JONSWAP}}(w)$ is the wave spectrum. The JONSWAP spectrum is used to characterize the wave amplitude ζ_a, which is described as

$$S_{\text{JONSWAP}}(w)=\frac{320H_{1/3}^2}{T_p^4}w^{-5}\exp\left[\frac{-1950}{T_p^4}w^{-4}\right]\gamma^A$$

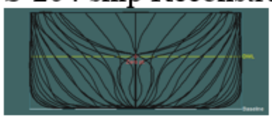




S-204 ship body plan [1]



S-204 ship Reconstruction



R_{calm} estimation by Holtrop method [2]

$$R_{calm}=(1+k)R_F+R_W+R_{APP}+R_A+R_B$$

R_{aw} estimation by Salvesen method [2]

$$\nabla^2\phi=0$$

$$R_{aw}=\frac{i}{2}\rho k\cos\beta\sum_{j=3,5}\left\{\zeta_j\iint_s\left(\phi_j\frac{\partial}{\partial n}-\frac{\partial\phi_j}{\partial n}\right)\phi_0^* ds\right\}$$

$$+\frac{i}{2}\rho k\cos\beta\iint_s\left(\phi_7\frac{\partial}{\partial n}-\frac{\partial\phi_7}{\partial n}\right)\phi_0^* ds$$

$$R_T=R_{calm}+R_{aw}+R_{wind}$$

Figure 1. The overall framework of the modelling approach

Model Validation

The S-204 container ship is used in the model validation [1]. Detailed ship information is shown in Table 1. Model validation results are shown in Figure 2 and Table 2. Figure 1 compares simulated and measured ship resistance in calm water. Table 2 compares simulated and measured ship resistance in uncertain ocean environments. It can be seen that the maximum error is less than 15 %, and the average error less than 10 %.

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Model Validation

Deadweight [ton]	23,400
Length [m]	204
Breadth [m]	30.8
Draught to design waterline [m]	9
Maximum draught [m]	10
Minimum draught [m]	6
Transverse wind area [m²]	756
Transverse wind area [m²]	3570
Number of blades	6
Propeller Diameter [m]	6.15
Trust Deduction Fraction	0.19

Table 1. The main dimensions of S-204 ship [1]

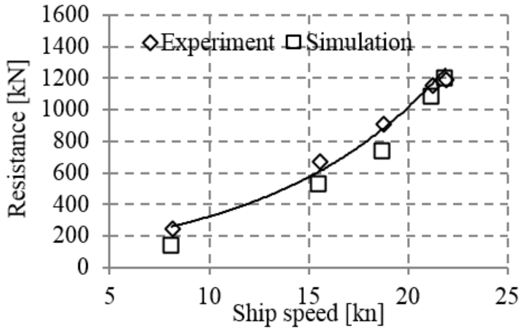

Figure 2. Comparison of ship resistance in calm water between simulation and experiment [1] under different speeds

Ship speed [kN]	Wind speed [m/s]	Wind direction [rad]	Wave height[m]	Wave period [s]	Wave heading [rad]	Total Resistance [kN]	
						Simulation	Experiment [1]
18.7	3.8	3.4	0.5	5	2.7	882	1012
20.5	7.1	5.5	3.0	6	0.5	1131	1128
19.7	7.6	1.1	1.5	4	2.7	1031	1081
19.1	9.5	1.0	3.5	7	2.5	1048	1118
18.8	13.0	0.9	6.0	9	2.6	1055	1042
18.7	6.2	0.1	4.5	8.5	3.0	958	978
14.8	19.1	3.1	6.5	10.5	3.1	1168	1131

Table 2. Comparison of ship resistance between simulation and experiment [1] in the different ocean environments

Resistance Estimation and Effect Analysis

Numerical simulations using the proposed approach are performed. The estimation results in the different conditions are illustrated in Figures 3-5. It is noted that

- Ship resistance substantially increases with ship speed. Wave significant height has a more significant effect to ship resistance in the low speed than in the high speed. (See Figure 3)
- Wave significant period has a positive effect to ship resistance. This effect is not influenced by ship speed. (See Figure 4)
- Ship deadweight has a significant effect on ship resistance in a relatively calm ocean environment. The effect decreases with ocean wave height increase. (See Figure 5)

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Resistance Estimation and Effect Analysis

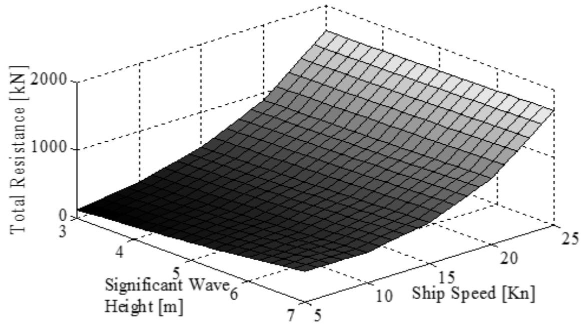


Figure 3. The estimation of the ship resistance under different speeds and wave heights

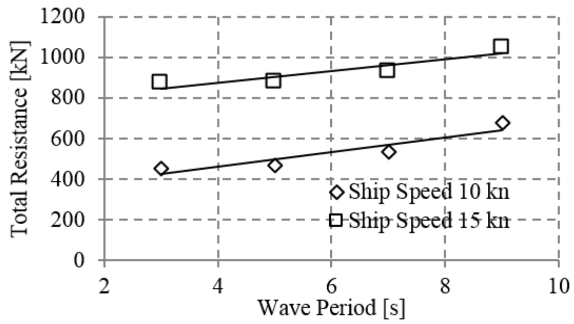


Figure 4. The estimation of the ship resistance under different wave periods

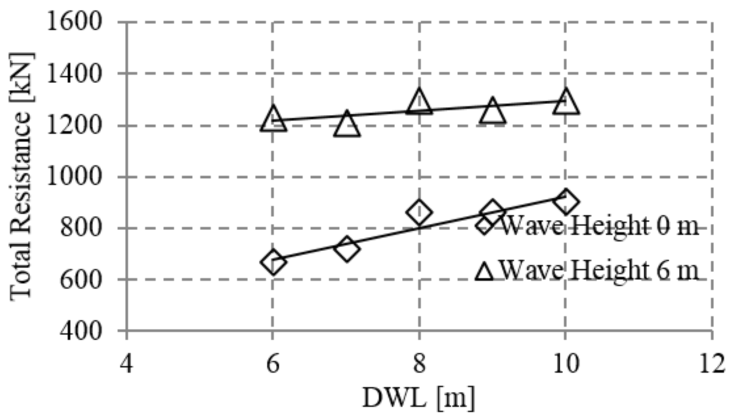


Figure 5. The estimation of the ship resistance under different draughts

Conclusion

In this study, a numerical approach is proposed to estimate ship resistance in uncertain ocean environments. The validation of the model is performed and find that the predicted ship resistance fits to the measured data well. Then, based on the proposed model, we further analyze the effect of ship speed, ocean wave and deadweight to ship resistance. It is found that the model is effective for ship resistance predication in different ocean environments.

Reference

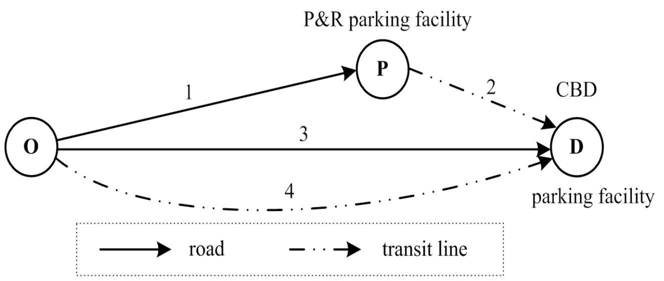
[1] J.M.J. Journée (2003). Review of the 1979 and 1980 Full-Scale Experiments Onboard Containership m.v. Hollandia. DUT-SHL Report 1349.

[2] J. Prpić-Oršić, O. M. Faltinsen (2012). Estimation of ship speed loss and associated CO2 emissions in a seaway. Ocean Engineering. 44: 1-10.

Research Highlight 2: Park-and-Ride Network Equilibrium with Heterogeneous Commuters and Parking Space Constraint, By Dr. Wang Hua (Track Leader: Associate Prof. Meng Qiang)

Introduction of Park-and-Ride Network

A schematic P&R network comprises of two bottleneck-constrained roads and two rail transit lines. Commuters are classified into three classes named by 1, 2 and 3 in accordance with their VOTs. Assumed that all these commuters have the same preferred arrival time at destination. The commuters can complete their travel journeys from the origin (home) to the destination (workplace) in morning commuting by any of the three paths - auto path, transit path and P&R (auto-transit) path.



The dynamic user equilibrium conditions with simultaneously path and departure time choices (DUE-PDC) satisfies the ideal principle proposed by Ran and Boyce (1996), stated as follows: for the commuters in each class traveling on each path, the total generalized costs incurred by commuters departing at any time are equal and minimal.

DUE-PDC Model:

$$\begin{cases} f_k^i(t)\cdot\left[u_k^i(t)-\mu^i\right]=0,\forall k,i,t \\ u_k^i(t)-\mu^i\geq 0,\forall k,i,t \\ \sum_k f_k^i(t)=q^i(t),\forall k,i,t \\ \sum_t q^i(t)=Q^i,\forall i,t \\ u_k^i(t)=g\left(C_k^i(t,\mathbf{f}),\mathbf{e}_k\right),\forall k,i,t \\ f_k^i(t)\geq 0, C_k^i(t,\mathbf{f})\geq 0,\mathbf{e}_k\geq 0\forall k,i,t \end{cases}$$

The main objective is to provide fresh insights into P&R network modeling of considering two influential factors: commuter heterogeneity and parking space constraint. Three contributions of this study:

(1) Derive P&R DUE commuting pattern with heterogeneous commuters;

(2) Investigate impacts of parking space constraint on the P&R DUE and the issue of non-unique equilibrium solution;

(3) Propose P&R parking schemes to evaluate the network performances in the worst case and the best case patterns.

Equilibrium Commuting Patterns -without parking space constraint

In DUE-PDC model, path travel times can be determined by two methods: (1) derive dynamic link travel time functions under departure time equilibrium, (2) use a dynamic traffic flow model such as cell transmission model to generate a unique mapping from path flows to path travel times (Szeto and Lo, 2004; 2006). In this study, we adopt the first approach, more precisely the ADL model proposed by Arnott et al. (1988), for its highly tractability and closed-form expression.

Travel time of riding transit is given as a constant without considering crowding effects. The transit link travel time function for commuter class i is expressed as:

$$p^i\left(T_{tr}^0\right)=\alpha_i T_{tr}^0$$

Equilibrium without parking space constraint

Generalized travel cost for auto path = auto travel time + gasoline expended ρ_{at} + parking fee at the destination τ_d

$$u_{at}^i=P^i\left(N_{at}^1,N_{at}^2,N_{at}^3,T_{at}^0\right)+\rho_{at}+\tau_d$$

Generalized travel cost for intermodal P&R path = costs by using auto + costs by taking transit (travel time and service charge) λ_{p+r} + P&R transfer waiting time t_w

$$u_{p+r}^i=\left[P^i\left(N_{p+r}^1,N_{p+r}^2,N_{p+r}^3,T_{pa}^0\right)+\rho_{p+r}+\tau_p\right]+\alpha_i\cdot t_w+\left[p^i\left(N_{p+r}^1,N_{p+r}^2,N_{p+r}^3,T_{pt}^0\right)+\lambda_{p+r}\right]$$

Research Highlight 2: Park-and-Ride Network Equilibrium with Heterogeneous Commuters and Parking Space Constraint, By Dr. Wang Hua (Track Leader: Associate Prof. Meng Qiang)

Equilibrium Commuting Patterns -without parking space constraint

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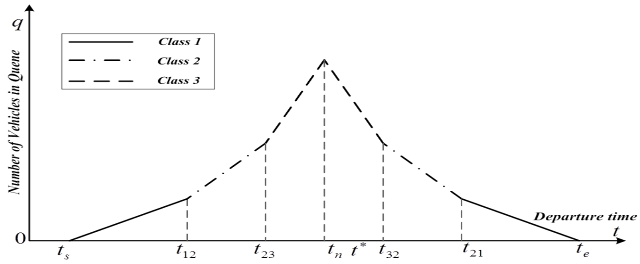
Travel time of riding transit is given as a constant without considering crowding effects. The transit link travel time function for commuter class i is expressed as:

$$p^i\left(T_{tr}^0\right) = \alpha_i T_{tr}^0$$

The 'isocost' equilibrium for three classes of commuters with different VOTs but the same preferred arrival time, γ_i / β_i is constant.



At the departure time equilibrium, the individual travel time for commuter in class i departing from the origin at time t on a particular bottleneck-constrained road (i.e., links 1 and 3):

$$\begin{cases} P^1\left(N_{rd}^1, N_{rd}^2, N_{rd}^3, T_{rd}^0\right) = \alpha_1 T_{rd}^0 + \dfrac{\beta_1\gamma_1}{\beta_1+\gamma_1}\dfrac{N_{rd}^1+N_{rd}^2+N_{rd}^3}{s} \\ P^2\left(N_{rd}^1, N_{rd}^2, N_{rd}^3, T_{rd}^0\right) = \alpha_2 T_{rd}^0 + \dfrac{\beta_2\gamma_2}{\beta_2+\gamma_2}\dfrac{N_{rd}^2+N_{rd}^3}{s} + \dfrac{\alpha_2}{\alpha_1}\dfrac{\beta_1\gamma_1}{\beta_1+\gamma_1}\dfrac{N_{rd}^1}{s} \\ P^3\left(N_{rd}^1, N_{rd}^2, N_{rd}^3, T_{rd}^0\right) = \alpha_3 T_{rd}^0 + \dfrac{\beta_3\gamma_3}{\beta_3+\gamma_3}\dfrac{N_{rd}^3}{s} + \dfrac{\alpha_3}{\alpha_2}\dfrac{\beta_2\gamma_2}{\beta_2+\gamma_2}\dfrac{N_{rd}^2}{s} + \dfrac{\alpha_3}{\alpha_1}\dfrac{\beta_1\gamma_1}{\beta_1+\gamma_1}\dfrac{N_{rd}^1}{s} \end{cases}$$

Generalized travel cost for transit path = travel time of riding transit + service charge of rail transit λ_{rt}

$$u_{rt}^i = p^i\left(T_{rt}^0\right) + \lambda_{rt}$$

The DUE-PDC model can be reformulated as a special deterministic tri-modal multi-class user equilibrium problem: **EM.NPS Model**:

$$\begin{cases} N_k^i \cdot \left(u_k^i - \mu^i\right) = 0, \forall k, i \\ u_k^i - \mu^i \ge 0, \forall k, i \\ \sum_k N_k^i = Q^i, \forall k, i \\ N_k^i \ge 0, \forall k, i \end{cases}$$

μ^i : equilibrium travel cost for class i

Q^i : commuting demand for class i

$k \in \{rd, p+r, rt\}$

The multi-class user equilibrium can be written as an equivalent variational inequality (VI) problem:

$$\left(\mathbf{N} - \mathbf{N}^*\right)^T \mathbf{u}\left(\mathbf{N}^*\right) \ge 0, \forall \mathbf{N} \in \Omega$$

$$\mathbf{u}\left(\mathbf{N}\right) = \left(u_{at}^1\left(\mathbf{N}\right), u_{at}^2\left(\mathbf{N}\right), \ldots, u_{rt}^3\left(\mathbf{N}\right)\right)^T, \mathbf{N} = \left(N_{at}^1, N_{at}^2, \ldots, N_{rt}^3\right)^T$$

Note: Since the function above is continuous and the feasible set constrained is a bounded convex region, there exists at least one solution to the VI problem according to Brouwer's fixed point theorem.

It is not difficult to obtain the Jacobian matrix, and to prove that it is not positive definite. Hence, the equilibrium solution for the VI problem may be not unique, depending on the network parameter setting.

the number of commuters for class i on the road

$N_{rd}^i\left(i=1,2,3\right)$: free flow travel time on the road

T_{rd}^0 : service capacity of the road bottleneck

s :

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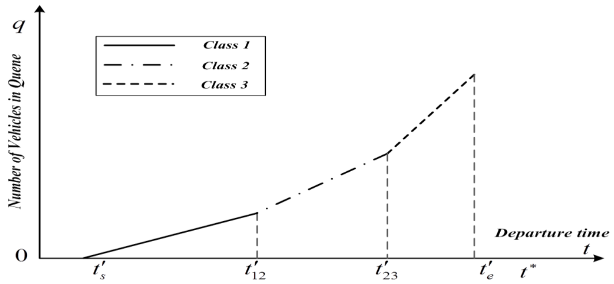
Equilibrium Commuting Patterns - with parking space constraint

Since the P&R scheme has a role to alleviate the problem of limited parking spots at CBD, we consider a scenario of insufficient parking spots at the destination.

Because of insufficient parking space, commuters need to compete for parking spots with an earlier departure time than the original scheduling. Assume that the queuing rule for all classes of the departure time in 'isocost' contour still holds when considering the impact of insufficient parking space at the destination.

New equilibrium 'isocost' contour with competition for parking spots, when the last commuter arrives early for work.



Let M_d denotes the limited parking spots at the destination;

t'_{12}, t'_{23} are the boundary times of departures between different Classes.

$$\begin{cases} (t'_e - t'_s)\cdot s = \sum_i N^i_{at} = M_d, \quad r(t) - s = \dfrac{\partial D(t)}{\partial t} = \dfrac{\beta_i}{\alpha_i - \beta_i}, t \in [t'_s, t'_e] \\ P^i(t) = \alpha_i \left(\dfrac{D(t)}{s} + T^0_{rd} \right) + \beta_i \left[t^* - \left(t + \dfrac{D(t)}{s} \right) \right], t \in t \in [t'_s, t'_e] \end{cases}$$

The new departure time equilibrium on the bottleneck-constrained roads is derived:

$$\begin{cases} t'_s = t^* - \dfrac{c^1 - \alpha_1 T^0_{rd}}{\beta_1}, \quad t'_e = t^* + \dfrac{M_d}{s} - \dfrac{c^1 - \alpha_1 T^0_{rd}}{\beta_1} \\ t'_{12} = t^* - \dfrac{c^1 - \alpha_1 (\eta_1 + T^0_{rd})}{\beta_1} - \eta_1, \quad t'_{23} = t^* - \dfrac{c^2 - \alpha_2 (\eta_2 + T^0_{rd})}{\beta_2} - \eta_2 \\ \eta_1 = \dfrac{\beta_1 c^2 - \beta_2 c^1}{\alpha_2 \beta_1 - \alpha_1 \beta_2} - T^0_{rd}, \quad \eta_2 = \dfrac{\beta_2 c^3 - \beta_3 c^2}{\alpha_3 \beta_2 - \alpha_2 \beta_3} - T^0_{rd}. \end{cases}$$

The integrated DUE with parking space constraint: although there is a binding parking space constraint, the path choice equilibrium on the P&R network still exists because of an extra earlier departure time generated to compete for the limited parking spots at the destination. Such equilibrium model can be formulated as following complementary conditions:

EM.PS Model:

$$\begin{cases} N^i_k \cdot (u^i_k - \mu^i) = 0, \forall k, i \\ u^i_k - \mu^i \geq 0, \forall k, i \\ \sum_k N^i_k = Q^i, N^i_k \geq 0, \forall k, i \\ \sum_i N^i_{at} = M_d \end{cases}$$

Where the equilibrium generalized travel cost for auto

$$u^i_{at} = P^i \left(N^1_{at}, N^2_{at}, N^3_{at}, T^0_{at} \right) + \rho_{at} + \tau_d + \pi^i, \forall \pi^i \geq 0$$

Optimal Parking Fee Scheme for P&R Network

The objective of the parking fee scheme is to minimize the total travel time (TTT) on the network:

$$TTT = \mathbf{C}(\mathbf{N})^T \cdot \mathbf{N}, \quad \mathbf{C}(\mathbf{N}) = \left(C^1_{at}(\mathbf{N}), C^2_{at}(\mathbf{N}), \ldots, C^3_{rt}(\mathbf{N}) \right)^T$$

Since the aforementioned equilibrium solution of the commuting pattern in EM.NPS or EM.PS may be not unique, therefore, it leads to a challenge of precisely evaluating the network performance. We here develop Min-Max and Min parking fee models for the worst-case and the best-case improvement schemes respectively.

Lower Level Mixed Integer Linear Program (MILP) is:

(1) Equilibrium constraints: the "if-then" complementary conditions are rewritten as

$$\begin{cases} L \cdot \sigma^i_k + \varepsilon \leq N^i_k \leq U \cdot (1 - \sigma^i_k), \sigma^i_k \in \{0, 1\} \\ L \cdot \sigma^i_k \leq u^i_k - \mu^i \leq U \sigma^i_k, \sigma^i_k \in \{0, 1\} \\ u^i_k - \mu^i \geq 0 \end{cases}$$

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Optimal Parking Fee Scheme for P&R Network

A: Min-Max model: worst-case improvement scheme

$$\min_{\tau_p}\left\{\max_{\mathbf{N}(\tau_p)\in\Omega^*(\tau_p)} \mathbf{C}\left(\mathbf{N}(\tau_p),\tau_p\right)^T\cdot\mathbf{N}(\tau_p)\right\}$$
$$s.t.\quad \tau_p\geq 0$$

B: Min model: best-case improvement scheme

$$\min_{\tau_p}\left\{\min_{\mathbf{N}(\tau_p)\in\Omega^*(\tau_p)} \mathbf{C}\left(\mathbf{N}(\tau_p),\tau_p\right)^T\cdot\mathbf{N}(\tau_p)\right\}$$
$$s.t.\quad \tau_p\geq 0$$

Both Min-Max and Min models can be decomposed into bi-level optimization programs. The upper level is to seek optimal parking fee and the lower level problem is to determine the worst/best-case network performance among multiple feasible equilibrium commuting patterns. The lower level problem can be transformed into an equivalent Mixed integer linear program.

(2) Demand conservation constraints

$$\begin{cases}\sum_k N_k^i = Q^i, N_k^i \geq 0, \forall k, i\\ \sum_i N_{at}^i = M_d\end{cases}$$

(3) Linear generalized travel cost functions

(4) Rewrite a linear objective function

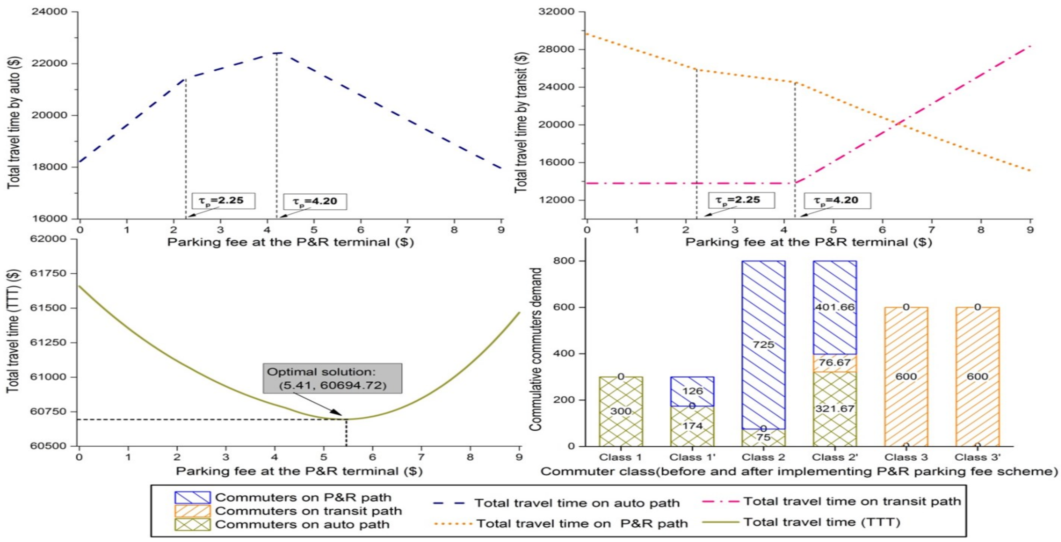
$$TTT=\sum_i Q^i\cdot\mu^i-\lambda_{rt}\sum_i N_{rt}^i-\left(\rho_{at}+\tau_d\right)\sum_i N_{at}^i$$
$$-\left(\rho_{p+r}+\tau_p+\lambda_{p+r}\right)\sum_i N_{p+r}^i$$

So far, the lower level problem is perfectly reformulated as a MILP and can be easily solved by optimization solvers, such as CPLEX. In this paper, both models are solved by a grid search procedure (i.e., numerically enumeration method), in view that the upper level problem only considers one design variable, parking fee.

Optimal Parking Fee Scheme for P&R Network

The numerical examples are carried out to demonstrate the effectiveness of the proposed models and show the importance of considering parking space constraint.

Effect of P&R parking fee scheme



(1) In general, the TTT functions for all three path are piecewise linear.

(2) The compulsory parking fee scheme enforces part of commuters divert from using P&R path to using other two paths so that the congestion in P&R path will be alleviated.

(3) At least 375 and 496 parking spots are needed before and after implementing parking fee scheme.

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Optimal Parking Fee Scheme for P&R Network

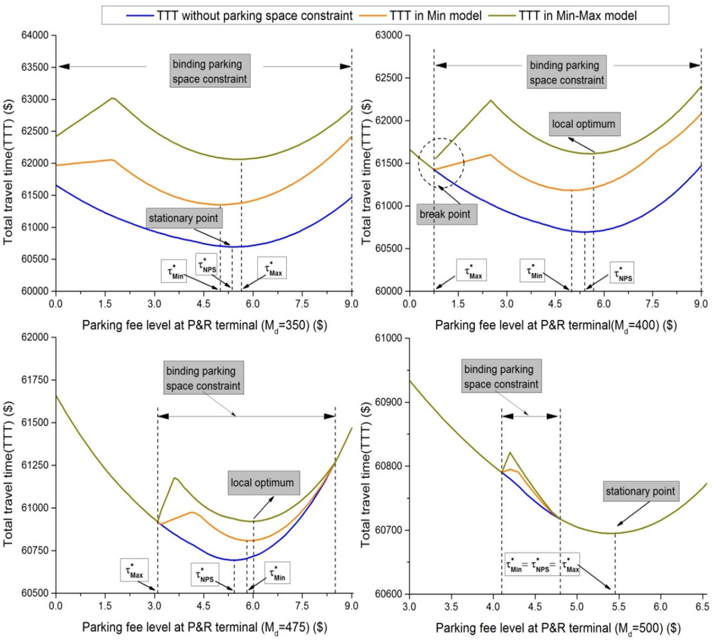
Impact of parking space constraint: the parking spots at the destination change from 350 to 525 that each step is 25. And, the P&R terminal has sufficient parking space.

1) Parking space constraint changes the equilibrium commuting patterns and leads to non-unique equilibrium solutions.

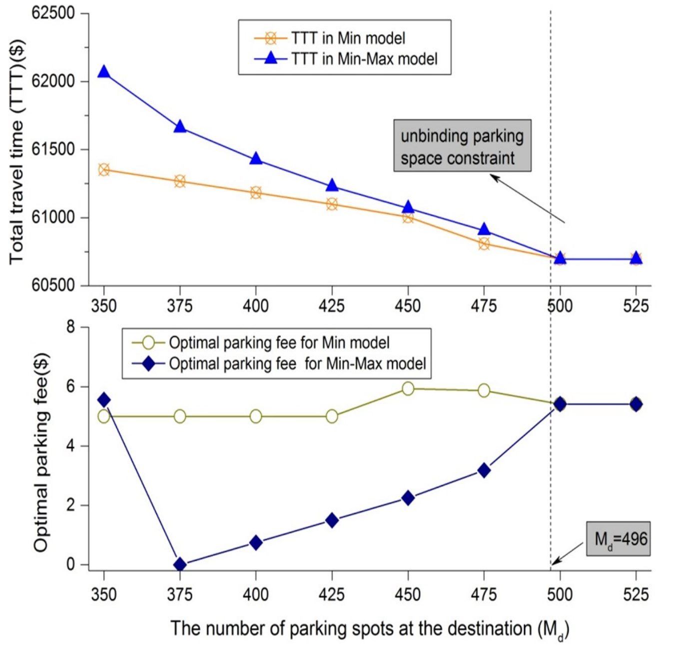
(2) Insufficient parking space at the destination yields somewhat adverse impact on the network performance because it restrains the commuters from choosing auto path freely. The commuters have to choose high-travel cost transit path or P&R path.

Parking space constraint is important for P&R network modeling and decision-making because of its impacts on changing path and departure time choices, and on ruining the continuity, differentiability and convexity of objective functions.

Four typical scenarios of parking space constraint



Solution results with different parking space constraint



Future Works:

The case of many-to-one OD pairs can be investigated through this schematic P&R network concept by considering each OD pair individually.

To address a more practical scenario, the crowding effects on rail transit line can be considered by relaxing the assumption of same preferred arrival time like Cohen(1987).

How to model a continuous distribution of commuter heterogeneity for P&R network analysis is an interesting extension.

A tradable parking credits distribution scheme such as that in Zhang et al. (2011) can be developed for the P&R network of improving network travel efficiency, especially when considering insufficient parking space.

Published Technical Papers (with Abstracts)

1. Xinjia Jiang, Ek Peng Chew, Loo Hay Lee, (2014), Innovative Container Terminals to Improve Global Container Transport Chains. ***International Series in Operations Research & Management Science Volume 220, 2015, pp 3-41***

Abstract:

A major objective of the practical implemented cordon-based congestion pricing schemes is to maintain the traffic conditions within the cordon area, which is rarely considered in most of the existing studies. Thus, this paper addresses the optimal toll charge pattern that can restrict the total inbound flow of each cordon to a predetermined threshold. The toll charges on all the entry links of one cordon are required to be identical, for the ease of implementation and users' recognition. The users' route choice behaviour is assumed to follow stochastic user equilibrium (SUE) with asymmetric link travel time functions. It is shown that such an optimal toll charge pattern can be attained by solving a SUE problem with side constraints. A variational inequality (VI) model is first proposed for the optimal toll pattern, where the monotone property of this model is rigorously proved. Then, a convergent self-adaptive prediction and correction method can be adopted for solving the VI model. It is shown that when used in practice, the solution method only needs traffic counts on entry links of each cordon.

2. Pedrielli G., S.H. Ng and Lee, L.H. (2014), Optimal Bunkering Contract in A Buyer–Seller Supply Chain Under Price and Consumption Uncertainty. ***Transportation Research Part E, accepted for publication. 27 pages.***

Abstract:

Bunker fuel constitutes about three quarters of the operational costs for liners. A strong effort is justified to define operational conditions and management strategies to minimize fuel–related costs, especially if the variability of fuel price is considered. Fuel sellers and liners use contracts to be guaranteed a refuelling quantity and control bunker price. We propose a game theory based approach to examine and optimize the parameters of a realistic bunkering contract. Under the proposed settings, the supplier and the buyer establish the bunker quantity and the price to maximize the expected profit and minimize the expected refuelling cost, respectively.

3. Wang, S., Liu, Z., Meng, Q., (2015), Segment-based alteration for container liner shipping network design. ***Transportation Research Part B, Vol. 72, pp. 128–145.***

Abstract:

Container liner shipping companies only partially alter their shipping networks to cope with the changing demand, rather than entirely redesign and change the network. In view of the practice, this paper proposes an optimal container liner shipping network alteration problem based on an interesting idea of segment, which is a sequence of legs from a head port to a tail port that are visited by the same type of ship more than once in the existing shipping network. In segment-based network alteration, the segments are intact and each port is visited by the same type of ship and from the same previous ports. As a result, the designed network needs minimum modification before implementation. A mixed-integer linear programming model with a polynomial number of variables is developed for the proposed segmented-based liner shipping network alternation problem. The developed model is applied to an Asia–Europe–Oceania liner shipping network with a total of 46 ports and 11 ship routes. Results demonstrate that the problem could be solved efficiently and the optimized network reduces the total cost of the initial network considerably.

Published Technical Papers (with Abstracts)

4. Jianlin Jianga, Loo Hay Lee, Ek Peng Chew, Chee Chun Ganb, (2015), Port connectivity study: An analysis framework from a global container liner shipping network perspective. *Transportation Research Part E: Logistics and Transportation Review, Volume 73, January 2015, Pages 47–64.*

Abstract:

This paper introduces an analysis framework for port connectivity from a global container liner shipping network perspective: it is defined in terms of the impact on the transportation network when the transshipment service is not available at the evaluated port. Under this framework, two models for port connectivity are introduced from transportation time and capacity. Compared with existing measures, the strength of our framework and models is not only that it provides scientific methods to compute port connectivity, but it is able to capture a global effect on how port connectivity contributes to the overall network for given shipping services.

5. Pedrielli, G., Matta, A. and Alfieri A., (2015), Integrated Simulation-Optimization of Pull Control Systems. *International Journal of Production Research. DOI: 10.1080/00207543.2014.997404.*

Abstract:

Pull policies are considered to be among the most efficient control strategy. Setting the correct parameters to maximise their efficiency is, however, not a trivial task. Simulation–optimisation techniques have received particular attention as a means to solve this problem. Nevertheless, they require the iterative solution of an optimisation model to generate the parameter values and a discrete event simulator to evaluate the resulting system performance. In the framework of simulation-optimisation, this paper proposes a combined solution of the optimisation and simulation problems for the optimal operation of pull control systems under several control strategies. Numerical experiments were performed to evaluate the performance of the proposed technique.

Conference Papers (with Abstracts)

1. G. Pedrielli, A. Matta, A. Alfieri, (2014), Time Buffer Control System for a multi–stage production line. ***The IEEE CASE Conference, 18-22 August, 2014, Taiwan Taipei.***

Abstract:

The Time Buffer Control System (TBCS) for coordinating multi-stage systems is introduced in this paper. The TBCS controls the release of jobs to synchronize the stages of a production line. Specifically, a set of time intervals called time buffers are adopted to delay the flow of jobs. The dynamics of the TBCS is described as well as the structural properties characterizing the policy. Numerical results are presented to evaluate the performance of a production/inventory system controlled by TBCS.

2. Matta, G. Pedrielli, A. Alfieri, (2014), Event Relationship Graph Lite: Event Based Modeling For Simulation–Optimization Of Control Policies In Discrete Event Systems. ***The Winter Simulation Conference. 7-10 December, 2014, Savannah, Georgia, USA.***

Abstract:

Simulation-optimization has received a spectacular attention in the past decade. However, the theory still cannot meet the requirements from practice. Decision makers ask for methods solving a variety of problems with diverse aggregations and objectives. To answer these needs, the interchange of solution procedures becomes a key requirement as well as the development of (1) general modeling methodologies able to represent, extend and modify simulation-optimization as a unique problem, (2) mapping procedures between formalisms to enable the use of different tools. However, no formalism treats simulation-optimization as an integrated problem. This work aims at partially filling this gap by proposing a formalism based upon Event Relationship Graphs (ERGs) to represent the system dynamics, the problem decision variables and the constraints. The formalism can be adopted for simulation-optimization of control policies governing a queueing network. The optimization of a Kanban Control System is proposed to show the whole approach and its potential benefits.

3. Chen, X., Pedrielli G, S.H. Ng, (2014), SNAT: simulation based search for navigation safety. The case of Singapore strait. ***The Winter Simulation Conference. 7-10 December, 2014, Savannah, Georgia, USA.***

Abstract:

As the bottleneck of the shipping routes from the Indian Ocean to the Pacific Ocean, the Singapore Strait is handling high daily traffic volume. In order to enhance navigational safety and reduce collisions at sea, several approaches have been proposed. However, most of the contributions adopt deterministic algorithms, failing to consider the stochasticity due to human behaviors of ship captains. Moreover, the effectiveness of these approaches is hindered by the fact that their focus is on providing a globally optimal safe set of trajectories to all vessels involved in encounter situations, almost neglecting each captain's perspective. We propose Safe Navigation Assistance Tool (SNAT), a simulation--based search algorithm to assist the captain by suggesting highly safe and robust maneuver strategies for conflict avoidance. Extensive numerical experimentation were performed proving the effectiveness of SNAT in reducing the number of conflicts, with respect to real data provided by the Automatic Identification System (AIS).

Conference Papers (with Abstracts)

4. Yuquan Du, Qiang Meng, Yadong Wang, (2015), Budgeting the fuel consumption of a container ship over a round voyage via robust optimization. ***The 94th Annual Meeting of Transportation Research Board, January 11-15, 2015, Washington, D.C..***

Abstract:

This paper proposes a practical fuel budget problem which aims to determine a group of bunker fuel budget values for a liner container ship over a round voyage under uncertainties caused by severe weather conditions. We consider the synergetic influence of sailing speed and weather conditions on ship fuel consumption rate when estimating the bunker fuel budget of a ship over a round voyage. To address the adverse random perturbation of fuel consumption rate under severe weather conditions, we employ the state-of-the-art robust optimization techniques and develop a robust optimization model for the fuel budget problem. However, algorithmic findings in the field of robust optimization provide a polynomial time solution algorithm, and we retrofit it to accommodate the proposed ship fuel budget problem. The case study on 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. Qiang Meng, Yadong Wang, Yuquan Du., (2015), Bunker procurement planning for container liner shipping companies: a multi-stage stochastic programming approach. ***The 94th Annual Meeting of Transportation Research Board, January 11-15, 2015, Washington, D.C..***

Abstract:

This paper investigates bunker procurement planning (BPP) problem arising from a container liner shipping company that plans to purchase bunker from both bunker futures contracts and the spot market in order to hedge the risk caused by the fluctuation and increasing of bunker price. An interesting multi-stage bunker procurement decision process for the BPP problem is developed to determine the monthly bunker procurement by allowing the shipping company to sign bunker futures contracts in the first stage and rebalance them in the subsequent stages. By assuming the stochasticity of bunker spot price, the BPP problem is formulated as a mean-variance minimization stochastic programming model. An approximation solution method to solve this model is designed by integrating random variable sampling technique, scenario tree generation and the quadratic programming approximation. Finally, numerical experiments demonstrate that the bunker procurement risk can be effectively hedged by using the proposed methodology. This study serves as a useful decision tool to plan bunker procurement for the container liner shipping companies.

6. Shuaian Wang, Yuquan Du, Hua Wang, Ying Yang, (2015), A collaborative mechanism between shipping lines and port operations in container handling. ***The 94th Annual Meeting of Transportation Research Board, January 11-15, 2015, Washington, D.C..***

Abstract:

The container handling rates at ports are input for container shipping operations planning by shipping lines. The handling rates are unilaterally determined by port operators. This paper points out that it may be possible for port operators to provide higher handling rates at some additional costs. The higher handling rates will enable ships to have more time sailing at sea, leading to less fuel consumption. The reduction in fuel costs for shipping lines may be more significant than the additional costs incurred by port operators. We therefore propose a practical and easy-to-implement collaborative mechanism between shipping lines and port operators, where the shipping lines compensate the port operators for their additional costs. As a result, the overall efficiency of container transportation is improved.

CMS Research Seminars

1. Continuous Multiple-Time-Grid Formulation in Mixed Integer Programming for Scheduling Problems, by Researcher Dr. He Yaohua (Track Leader: Prof Fwa Tien Fang)

Seminar Abstract:

Scheduling problems can be formulated as mixed integer programming models. Sequence variables (SV) along with Big M constraints are widely used in classical scheduling formulation. Big M constraints result in long computational time. This presentation introduces a method based on Continuous Multiple-Time-Grid Formulation to totally or partially avoid BIG M constraints. The method is illustrated with two scheduling problems. Computational tests with the examples indicate that the proposed approach is able to reduce computational effort by several orders of magnitude compared with the SV models.

2. A Review on Commercial Viability of Trans-Arctic Shipping Routes, by Researcher Ms. Zhang Yiru (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

There has been increasing number of studies evaluating the profitability of trans-Arctic routes since it is the primary concern of the shipping industry. In our project, we are interested in the cost-competitiveness of three trans-Arctic routes, in relative to traditional trade routes. However, we note that there is no unified way for viability analysis; researchers have evaluated the cost competitiveness of different routes against their respective standards and based on varied assumptions. In this presentation, we would like to analyze a few chosen models on commercial variability in great details to identify their respective advantages and disadvantages. Thus, lessons can be drawn in developing our own model.

3. A brief review on Simulation Optimization & Integrated Sim-Opt, by Researcher Dr. Pedrielli Giulia (Track Leader: Associate Prof Lee Loo Hay)

Seminar Abstract:

Simulation Optimization is acquiring always more interest within the simulation community. It is being particularly successful to solve optimization problems where, potentially, both the objective function as well as the constraints cannot be evaluated through closed form formulas, but require the use of simulation to obtain a point estimate of their value. Both deterministic and stochastic functional are of interest. Several techniques have been proposed to solve this family of problems and they typically use two different and separate modules, each based on a specific technique, working iteratively. A simulation module evaluates the system performance and an optimization module generates the candidate solutions. The large number of iterations, usually characterizing the described loop, can be partially ascribed to the lack of system dynamics modeling within the optimization module (justifying the presence of an external performance evaluator). These main techniques are briefly reviewed and the last advances in simulation optimization are highlighted including the speaker research on models for the integrated simulation optimization of Discrete Event Systems.

CMS Research Seminars

4. Numerical Simulation for Stability Analysis of Marine Structures, 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. The focus of this talk will be on the overview of numerical simulation for stability analysis of marine structures. A case study is given to illustrate this analysis procedure.

5. Introduction of sea ice model and its evaluation, by Researcher Ms. Xu Min (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

In order to gain a better understanding about the change of sea ice conditions in Arctic, numerical sea ice models have been used to perform the variability analysis of sea ice. In this project, we focus on the prediction of sea ice concentration and thickness in the long term simulations (century time scale, out to 2100 and beyond). In this presentation, a brief review of model performance and evaluation will be given as well, which may help to choose the "best" models to analyses the physical viability of Trans-Arctic sea routes.

6. Mooring load analysis for side-by-side mooring system at quay, by Researcher Mr. Zhou Kang (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

Stepping into 21st century, the shipping always has a trend: the vessels become larger, more standardized and more specialized, which propose the safety challenge of berthing. Especially when shipyards tend to adopt side-by-side mooring pattern in order to increase the usage ratio of berths, how to keep SBS mooring at quay safe has become a hot issue.

7. Optimal parking pricing in the many-to-one park-and-ride network with parking space constraints, by Researcher Dr. Wang Hua (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

This talk introduces an optimal parking pricing problem in a many-to-one (multiple origins to one destination) park-and-ride (P&R) network taking into account practical parking space constraints. The proposed problem aims to minimize total travel cost by setting optimal parking fees at P&R terminals. It is formulated as a bi-level programming model that comprises an upper level problem of determining optimal parking fees and a lower level problem of characterizing commuters' travel equilibrium of departure time and path choices. For the lower level problem, we develop a user equilibrium model to address the commuting patterns with/without parking space constraints in the many-to-one P&R network. Meanwhile, the parking spot ending time is used to describe how commuters from different origins compete with one other for the limited parking spots at the destination.

CMS Research Seminars

8. SNAT: simulation based search for navigation safety. The case of Singapore strait, by Researcher Dr. Pedrielli Giulia (Track Leader: Associate Prof Lee Loo Hay)

Seminar Abstract:

As the bottleneck of the shipping routes from the Indian Ocean to the Pacific Ocean, the Singapore Strait is handling high daily traffic volume. In order to enhance navigational safety and reduce collisions at sea, several approaches have been proposed. However, most of the contributions, adopt deterministic algorithms failing to consider the stochasticity due to human behaviors of ship captains. Moreover, the effectiveness of these approaches is hindered by the fact that their focus is on providing a globally optimal safe set of trajectories to all vessels involved in encounter situations, almost neglecting each captain perspective. We propose Safe Navigation Assistance Tool (SNAT), a simulation based search algorithm to assist the captain suggesting highly safe and robust manoeuvre strategies for conflict avoidance. Extensive numerical experimentation has been performed proving the effectiveness of SNAT in reducing the number of conflicts, with respect to real data provided by the Automatic Identification System (AIS).

9. Singapore's Air Industry - 50 Years of Development, By Researcher Mr. Yong Kuan Chen (Track Leader: Dr. Chia Lin Sien)

Seminar Abstract:

Singapore will hit its 50th Anniversary soon. In conjunction with the event, we plan to explore the air industry of Singapore, for both passenger and cargo, to understand how it started, how was it developed, and how it should go from where we are today.

10. Bicycle detection and tracking using computer vision for bicycle driving behavior study, By Researcher Dr. Zhang Liye (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

Current concerns surrounding air pollution, climate change, rising gasoline consumption and urban congestion could presage a substantial increase in the bicycle mode share. However, stat-of-the-art methods for the safe and efficient design of bicycle facilities are based on deep understanding of the bicycle driving behavior. Compared with driving behavior of motor vehicles, research on bicycle driving behavior is extremely scarce. Most of the current models are developed based on the models for depicting motor vehicle behaviors. However, some assumptions of these models seems dubious, as the significant differences between the driving behaviors of bicycles and motor vehicles. Furthermore, most of the existing models are not validated with actual data. Thus, considering the psychological and physiological process of the bicycle driving behaviors, the concept of bicycle domain will be proposed. Then, the bicycle driving behavior model based on bicycle domain and optimal decision theory will be built. The bicycle trajectory is the basis for this research. In this presentation, some preliminary research results of bicycle traffic data collection will be introduced. It mainly includes three components: bicycle headway detection using virtual-loop method, bicycle trajectory collection by bicycle detection and tracking, and 3D-reconstruction of bicycle trajectory data.

CMS Research Seminars

11. Ship fuel efficiency models and some empirical findings, By Dr. Du Yuquan (Track Leader: Associate Prof Meng Qiang)

Seminar Abstract:

In our recent collaboration with APL fuel efficiency team, we developed some containership fuel efficiency models for voyage performance analysis. These nonlinear regression models can quantitatively capture the relationship between fuel consumption rate of a ship and several determinants, such as sailing speed, displacement and weather/sea conditions. The first model proposed reflects the influence of sailing speed and displacement on ship fuel consumption rate, while the other two models additionally take into account the impacts of weather/sea conditions. We will report our empirical findings based on some shipping log data collected from our industrial collaborator. At last, we will demonstrate a possible way to apply these models in voyage planning. This study is supported by the joint research project with APL: "Big Shipping Log Data Driven Ship Fuel Efficiency Analysis and Management: Model Building & Software Development" funded by NOL Fellowship Program.

12. Modulation of Vessel Propulsion System in extreme sea condition, by Researcher Dr. Zhao Feiyang (Track Leader: Assistant Prof Yang Wenming)

Seminar Abstract:

Accurate prediction of ship's hydrodynamic behaviour under heavy weather conditions is essential for the power management system to optimized fuel consumption. Severe vessel motion and wave will bring the thrusters closer to the water surface and make them more susceptible to ventilation, which may cause large loss of propeller thrust and possibly damaging dynamitic loads. Therefore, voluntary modulation of vessel propulsion system should be taken when the freak wave was detected in order to minimize thrust loss and improve propulsion efficiency. In this study, the vessel speed was modulated step by step according to the ship behaves after the freak wave was detected. Eventually, the modulation process of shaft speed could be obtained under variety propeller submergence induced by different wave conditions.

13. Ship trim optimization, By Researcher Dr. He Yaohua (Track Leader: Prof Fwa Tien Fang)

Seminar Abstract:

Ship trim optimization is one the most effective approaches for enhancing ship fuel efficiency. This presentation will introduce how trim change affects ship resistance and propulsive efficiency through a range of trim-dependent factors, including the basic physical principles and quantitative analysis. Quantitative data can be obtained from model tests, CFD simulations or in-service tests for a wide range of speeds, drafts and trims. With the quantitative data, the complex trim curves are traditionally represented by mathematical regression models solved by gradient-based algorithms for optimum trim. However, "black-box" models built up by machine learning approaches can be more accurate than the regressive models. To solve the "black-box" models, intelligent solution algorithms need to be developed.

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