Simulation-based vessel operation for virtual ship design testing

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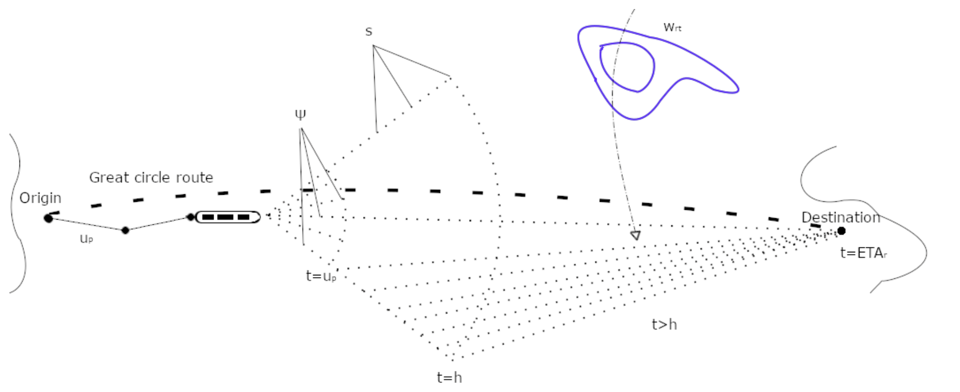
Introduction

It is necessary to assess the operational requirements and environment the ship will operate in, to develop a feasible technical design and to economically justify the viability of the design proposal (*Chapter 9 - Ship design, construction and operation* 2008) . Design performance are highly dependent on the operating profile of the vessel, i.e. where, when and how it will sail. Today vessel design is commonly tested in calm water and a selection of sea states. This makes it difficult for realistic performance evaluation, knowing ships are exposed to many sea states during a voyage. Hence, the ability to virtually demonstrate effects of potential design changes for vessels in operation, can represent a significant competitive advantage towards developing innovative ships that are energy efficient and have increased operability. **Background:** This thesis is based on the sea passage scenario generator presented in Sandvik et al. (Not published) related to ship system integration and validation for SFI Smart Maritime.**Objective:** Simulate operational decisions for virtual testing of ships designs, focusing on route and schedule disruption, and validate through comparison with full-scale measurements.

Case

A voyage from Shanghai to Panama in January with full-scale measurements available for comparison is used as case study.

Simulation Model



The voyage schedule is set by assuming the ship follow the great circle route at a given target speed. A set of candidate routes are generated by a given heading separation ω and route segment S. We assumed that a reliable weather forecast for the next h hours are available. For t>h statistical estimates for vessel fuel consumption is used. The vessel maintains a constant heading and speed for u_p hours, before the route and speed is re-evaluated. Occurring sea states during sailing may cause involuntary speed loss, depending on installed power or voluntary speed loss initiated by the captain, set according to *Assessment of ship performance in a seaway* (1987).

Optimisation Procedure

The objective is to complete the voyage with a minimum amount of fuel and schedule disruption:

$$min \sum_{r \epsilon R} \left(Fc_r^{t<h} + Fc_r^s + Cd_r \right) x_r \qquad (1)$$

where $Fc_r^{t<h}$ is the fuel cost for $t < h$ in route r, $Fc_r^{t>h}$ is the statistical fuel cost for $t > h$ in route r, Cd_r is the delay cost for route r and x_r is a binary variable that is 1 if route r is selected.

References

Assessment of ship performance in a seaway (1987).

Chapter 9 - Ship design, construction and operation (2008), *in* A. F. Molland, ed., 'The Maritime Engineering Reference Book', Butterworth-Heinemann, Oxford, pp. 636 – 727.

Sandvik, E., Nielsen, J. B., Asbjørnslett, B. E., Pedersen, E. & Fagerholt, K. (Not published), 'Operational sea passage scenario generation for virtual testing of ships using an optimization for simulation approach'.

Acknowledgements

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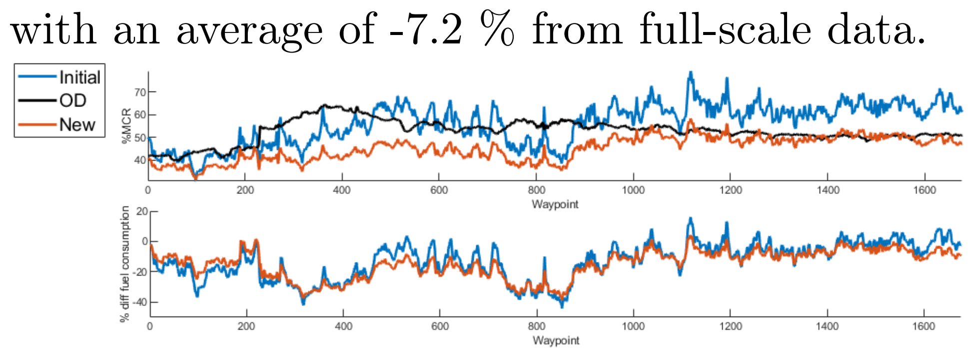
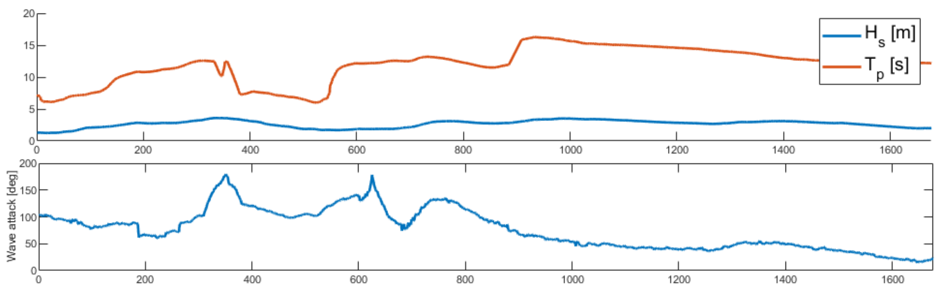
Ship Operation Model

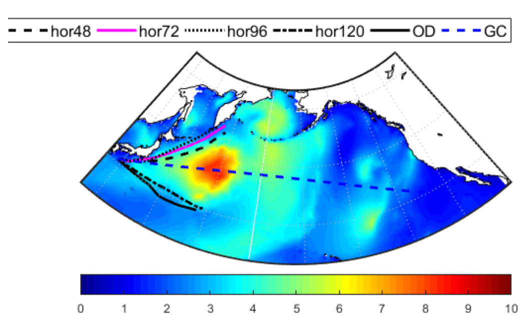
A general cargo carrier ship design with available towing tests for calm water resistance measurements, propeller open water tests, propulsion tests and machinery shop test has been used. For calculation of short-term added resistance coefficients due to waves, the generalised approach of Gerritsma and Beukelman by Lukakis and Sclavounos, covering oblique waves is applied. To correct for ideal circumstances under model tests, the initial model was compared with full-scale data for calm seas. The corrected model display similar behavior as full-scale data for wave attack angles below 50 degrees. The specific fuel oil consumption curve were increased with about 25 %, but still differs with an average of -7.2 % from full-scale data.

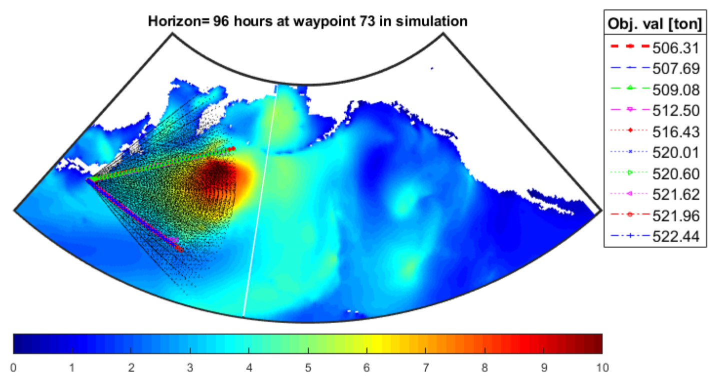


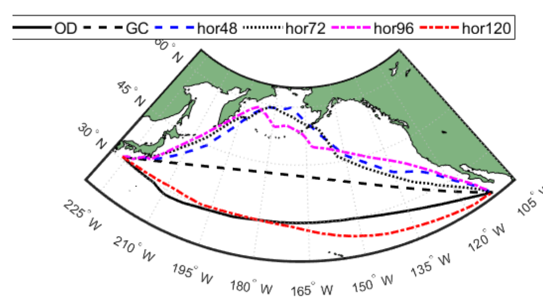


Operational Simulations

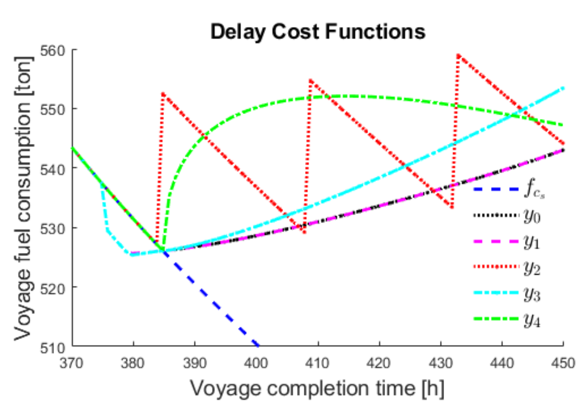
Wave forecast: The observable horizon represents the future time we can assume weather forecasts are reliable. In reality the horizon will depend on the captains ability to interpret weather forecast and experience with sailing in the area. The impact on simulated voyage routing due to length of observable horizon is displayed in the graphs below. For h $\leq$ 96 hours, the ship chooses to go north of the great circle route. When the horizon is 120 hours, it chooses to go south of the great circle route to avoid high sea states on great circle route, as did the actual Ship, OD. The two routes south of the great circle obtains the shortest distance of sailing, duration and fuel consumption. The picture in the middle illustrates the critical route choice for horizon 96 with ten best route choices in colour. The contour plots display Hs.

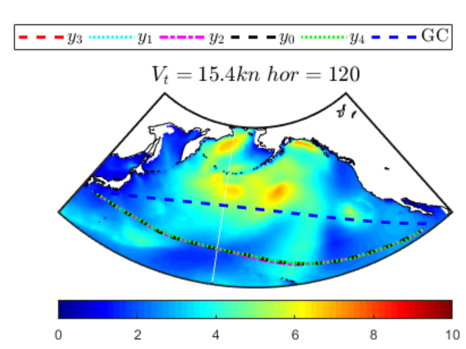


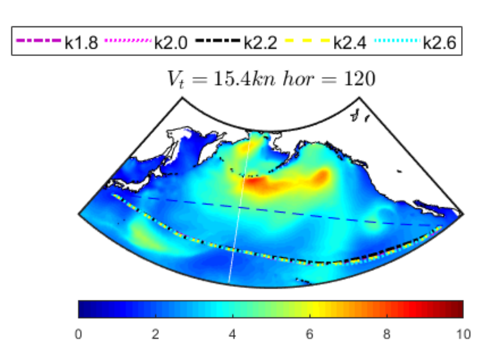




Cost Function analysis: The delay cost in the objective function represents the consequences of schedule disruption. Depending on the ships mode of operation, delayed arrival may lead to contracted fees for delayed cargo, extra cost for crew and cargo handling, schedule disruption and lost day-rate income. Five types of cost functions is tested on the simulator as well as a sensitivity study for increasing slope values for the linear cost function y_0. Function y_1 and y_3 reward early arrival while y_2 represents a contractual day-rate fee for delays. Only small deviations in operational parameters are found when increasing the slope of the linear cost function, and the routes approximately follow the same path. y_1 and y_3 arrive about 10 hours early, while the others arrive on-time. Operational parameters are found to be similar in all cases, but lowest for y_0, which is the one maintain the lowest speed. y_1 and y_3 has a slightly higher speed than the other options due to rewarded early arrival.







Conclusion The ship model validity decreases for following seas and stern quartering seas. The length of the observable horizon is critical for route selection while cost functions analysis so far indicate route selection for a horizon of 120 hours, display changes in speed and minor changes for second half of sailing.