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Michael John Francis Rustell

Aurora Orsini

Soon-Thiam Khu

Yaochu Jin

Ben Gouldby

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OPTIMIZING MARITME TERMINAL INFRASTRUCTURE SUBJECT TO UNCERTAINTY

MICHAEL RUSTELL (1,2), AURORA ORSINI (1), SOON-THIAM KHU (2), YAOCHU JIN (2), BEN GOULDBY (1)

(1): HR Wallingford, Howbery Park, Wallingford, OX10 8BA, UK

(2): University of Surrey, Guildford, Surrey, GU2 7XH, UK

This paper describes a hydroinformatic model for generating a Pareto set of LNG terminal layouts that are subject to uncertainty using a multi-objective genetic algorithm. The NSGAII is used to select parameters that propagate through a bespoke LNG terminal design algorithm which includes a Monte Carlo simulator to estimate the uncertainty in each concept. This allows the trade-off between cost and risk to be explored at the earliest stage of design. The results of a case study indicate that nearshore terminals typically have lower capital costs but higher maintenance costs and more uncertainty. The paper concludes that in the example site used, locating the terminal 1000m offshore results in an optimal compromise between cost and risk.

INTRODUCTION

During the initial design stage, engineers start to understand the constraints and establish the conceptual form. Traditionally, decisions are made using judgment, intuition and experience gained from similar projects. Whilst robust designs are possible, only a handful of concepts can be considered due to time and financial constraints, leading to the potential of leaving many good and possibly better concepts undiscovered.

When designing structures in the coastal environment, significant uncertainty exists with respect to the data and models used to estimate structural response. This is often dealt with through conservative (deterministic) design protocols although there are also probabilistic methods such as FORM, SORM, partial factors and Monte Carlo simulation.

This paper introduces a decision support system for the design of a liquefied natural gas (LNG) terminals that are subject to uncertainty. A bespoke model simulates environmental processes and automates design of the LNG terminal. The Monte Carlo method is used to sample from distributions that represent material costs, producing a probability distribution of the estimated capital and maintenance costs. A multi-objective genetic algorithm is used to generate a Pareto set of solutions that minimise capital cost, maintenance cost, uncertainty and berth downtime simultaneously.

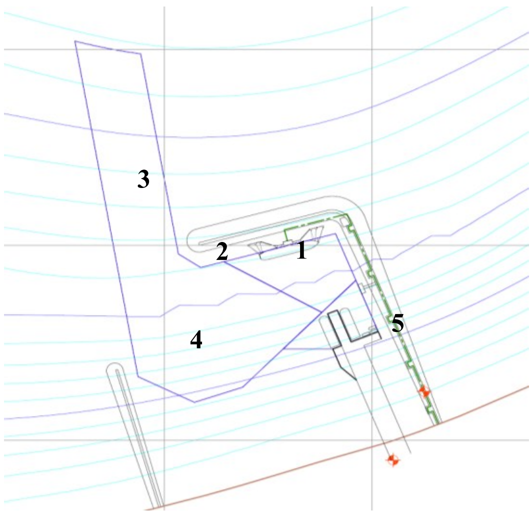
Background

An LNG terminal is a facility designed for either export or import of natural gas as a cryogenic liquid. LNG terminals are complex facilities, however four are the key structures are heavily influenced by the location of the vessel berth: the channel, basin, breakwater and product loading facility (PLF) (Figure 1).

The further offshore the berth, the longer the PLF and larger the breakwater cross-section (which increases exponentially with depth). Nearshore locations require a longer access channel and more voluminous basin which can substantially increase the capital and maintenance dredging costs. The breakwater must protect the vessel from oncoming waves:

a longer breakwater will provide more berth protection but the increase in cost and this must be considered with respect to the level of annual downtime the berth will incur.

Often the most significant uncertainty resides in the estimate of the initial cost of the channel and the maintenance cost due to sediment infill [2]. Nearshore terminals require more frequent dredging and often carry more risk due to the uncertainty involved with estimating dredge volumes and sediment infill rates, but may actually be most economical in the long run. Judging the optimum berth location in terms of capital and maintenance cost is one of the most important decisions of the design process. This importance is intensified by the inherent uncertainties which must also be considered. The need to enhance the design process by investigating where cost uncertainties reside and how the design can be optimized is evident.



Legend

1. Berth - Mooring the vessel and restricting its movement to allow safe loading and unloading.
2. Breakwater - Protect the berth against waves.
3. Channel - Provide safe navigation to and from the berth until the vessel is in naturally deep water.
4. Basin - For turning and maneuvering of vessels to and from the berth using tug boats.
5. PLF – Transfer LNG from the onshore plant to the berthed vessel.

Figure 1. LNG terminal with berth 1150m offshore

METHODOLOGY

The model will be used to explore how the capital cost, maintenance cost, uncertainty and berth downtime are affected by how far offshore the terminal is situated. The NSGA II [1] will be used to explore the multi-dimensional search space, aiming to simultaneously minimise capital and maintenance costs, uncertainty and berth downtime. The NSGA II will run for 100 generations of 150 chromosomes, propagating parameters through a bespoke LNG terminal design algorithm to produce each chromosome (see [2] for more detail on the design algorithm). To estimate the uncertainty of each design, probability distributions of material costs will be sampled using the Monte Carlo method and applied to the material volumes. This produces a mean capital cost and normalized standard deviation – *coefficient of variation* (CoV) for each design. The maintenance cost is calculated as 1% of the capital cost, discounted for present value for the breakwater and PLF and is based on the cost of removing deposited sediment that builds up in the channel and basin.

DISCUSSION OF RESULTS

A series of Pareto curves representing the multi-dimensional surface and box and whisker plots showing the result distributions are presented in Figure 2. The results show well-defined Pareto fronts indicating that explicit trade-offs between objectives exist.

Figure 2(1) shows that uncertainty can be reduced with higher initial capital expenditure and Figures 2(4) and 2(6) confirm that the uncertainty is being driven by the

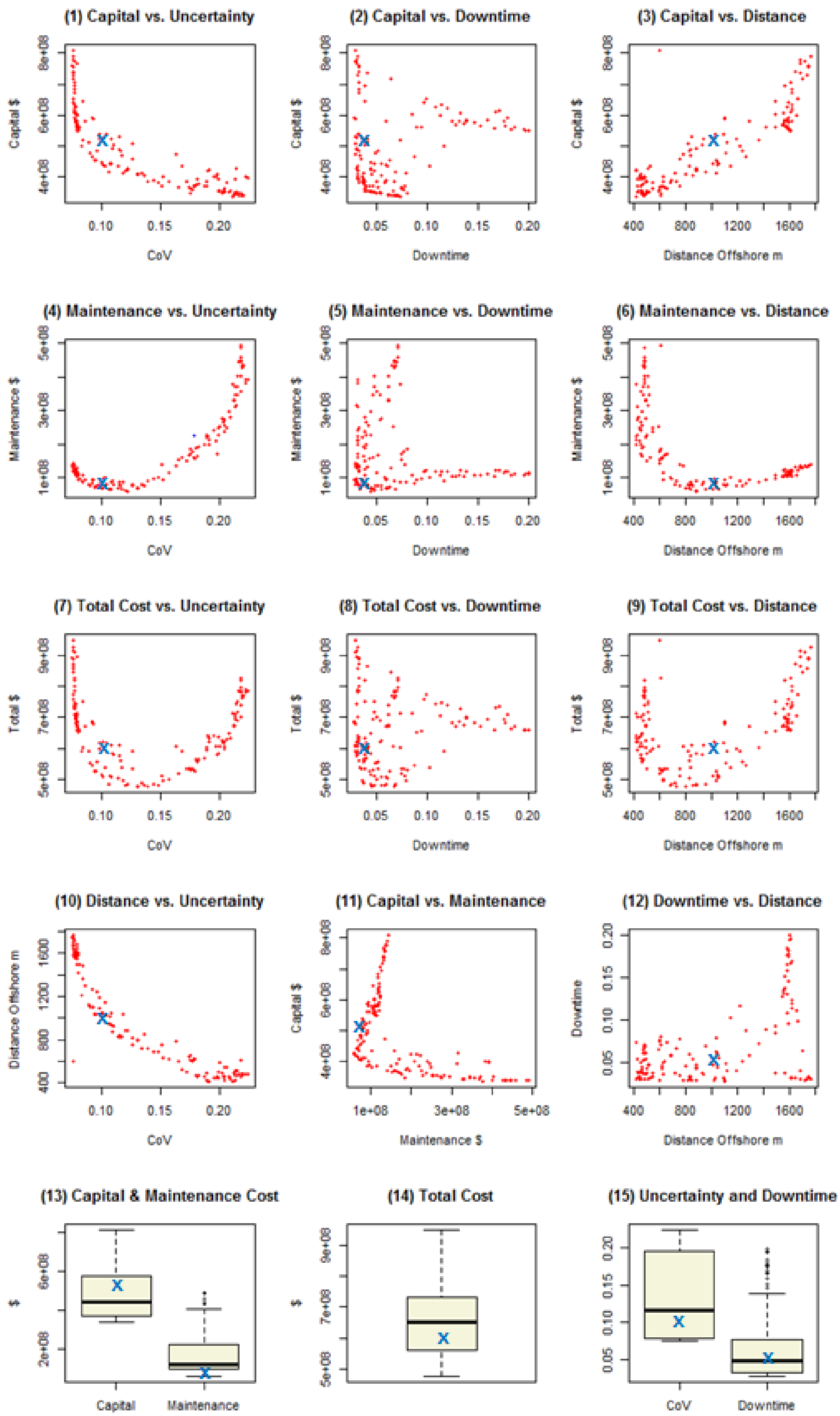


Figure 2. Pareto curves and box plots of results

cost of maintenance dredging in the nearshore where sediment transport is increasingly affected by wave interaction. The distance offshore is positively correlated with capital cost (Figure 2(3)) and negatively correlated with maintenance cost (Figure 2(6)). Between 800m and 1200m offshore, the maintenance cost is minimized, but starts to rise when the terminal is located more than 1400m offshore due to the exponential relationship between the breakwater cross-section and water depth. The relationship between capital and maintenance shows that there are solutions that are highly optimised in both objectives (Figure 2(11)). Terminals further than 700m offshore have increasingly lower uncertainty but increasingly higher capital and maintenance costs (Figure 2(10,11)).

Terminals with >5% downtime can incur penalties for being unable to provide safe berthing conditions so it is wise to consider 5% as a maximum. Figure 2(2) shows a bimodal correlation between capital and downtime and Figure 2(3) shows downtime decreasing with the distance offshore, likely due to minimization of the breakwater length (and hence cost) in deeper water. Correlation also exists between maintenance and downtime (Figure 2(5)) however this is indirect as maintenance cannot explicitly affect downtime in the model.

When the capital and maintenance costs are combined, a compromise can be found with, uncertainty & distance (Figure 2(7,8)) at around 1000m offshore (Figure 2(9)), which would have a layout similar to Figure1 but with a slightly longer channel and shorter trestle. A solution that reasonably minimizes each objective is indicated as 'x' on each graph in Figure 2. This solution is in 1000m water depth and although Figure 2(3) shows that there are solutions that minimize capital cost further, these solutions would also incur greater uncertainty which could easily translate into higher costs Figure 2(1).

Figures 2(13,15) show the distributions of the four objectives and total cost (Figure 2(14)). The value of the selected solution in each objective is shown to be at least as optimal as the median in all objectives but capital (Figure 2(13)) however this is compensated by the lower maintenance cost which translates into a low total cost (Figure 2(14)) and a relatively low amount of uncertainty (Figure 2(15)).

CONCLUSION

The NSGA II successfully generated a diverse solution pool with terminals located up to 1800m offshore. Nearshore solutions incurred higher maintenance costs and uncertainty but lower capital costs. In the example used, the most optimal compromised solutions are situated around 1000m offshore. Using this model at another site may lead to different conclusions as site specific data is required for the results to be valid.

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