Mingxin Li (TU Delft) wins Ph. D. Thesis Award 2024

Towards Closed-loop Maintenance Logistics for Offshore Wind Farms: Approaches for Strategic and Tactical Decision-making

Winning the Ph. D. Thesis Award 2024

This thesis addresses maintenance issues in a very important, fast-growing part of the Dutch and European economy, offshore wind farms. In the coming decade, the installed base of these windfarms will increase multifold and so will the challenges involved in maintaining them well. The location of these assets at sea creates unique, and therefore underresearched, challenges for maintenance.

It takes considerable time and effort for transport to these windturbines, and it requires also good weather conditions. Uncertainties and associate risks abound. Because this is a relatively new industry, we know very little about optimal maintenance policies across the life cycle of windturbines and wind parks. This Ph.D. thesis rises to these challenges, and introduces the notion of adaptive maintenance policy, so-called close-loop maintenance logistics. Here, as time goes by, the maintenance policy mix is evaluated and, if appropriate, updated.

Close-loop maintenance logistics. Close-loop maintenance logistics refers to a system of managing the flow of materials, equipment, and information within a closed loop or circuit, typically within a manufacturing or service environment. Li; "In the context of digitalization and Smart Industry, decision-makers can access real-time information about the status of offshore wind turbines and relevant data. This opens up the possibility of achieving a fully closed-loop maintenance logistics. A fully closed-loop maintenance logistics architecture implies that the decisions at the lower decision-making levels are made under the guidance of the decisions at the higher level, while higher-level decisions consider the feedback of lower-level decisions". The entire architecture is able to continuously update maintenance strategies and resource organization based on health prognostics, new Reliability, Availability and Maintainability (RAM) data, available maintenance resources, and real-time maintenance situations, according to Li.

What this has to do with Maintenance. Due to the complex marine environment, the scarcity of RAM data, the stochasticity in maintenance operations, offshore wind farm maintenance logistics suffer from a high degree of uncertainty. A closed-loop maintenance logistics architecture can coordinate decision-making across strategic, tactical, and operational levels. Li; "By continuously updating decisions, this architecture adapts to the dynamic maintenance scenarios and mitigates the negative effects of uncertainty on decision-making. This approach aims to reduce the O&M costs of offshore wind sector and enhance power generation efficiency in the era of Industry 4.0".

In this system, products or components are returned to the manufacturer or service provider after use, where they are repaired, refurbished, or recycled. This approach aims to minimize waste, maximize resource efficiency, and reduce environmental impact by extending the lifespan of products and components through maintenance and reuse rather than disposal.

Problems to be solved. Li looks at these new and fascinating issues from a hybrid perspective, including both technical and managerial factors. He properly employs a variety of operations research methods to perform the analyses required. Indeed, this is research that is at the same time well grounded in truly significant real world maintenance issues of today and in sound scientific research methods.

What are we talking about? "My thesis aims to address the main research question 'How to improve effectiveness of maintenance strategies and resource organization for offshore wind farms and move towards a closed-loop decision-making approach'?. To address the main question, Li's thesis encompasses the five aspects. Firstly, at the strategic level, a predictive opportunistic maintenance strategy that incorporates health prognostics and economic dependence is proposed. By integrating a simulation-based model with meta-heuristic algorithm, the optimal maintenance strategy is identified.

Subsequently, a probabilistic uncertainty modeling approach is introduced to characterize the parameter uncertainties within the model. A multi-objective optimization method is employed to determine the optimal decisions in the presence of conflict between multiple objectives. The impact of uncertainty on O&M costs and decision-making is quantified.

3rd, 4th and 5th aspect. At the tactical level, for two critical maintenance resource, i.e., spare parts and service vessels, simulation-based models are developed to organize maintenance resources, and the most cost-effective inventory policies and vessel fleet configurations are found by optimization.

Finally, using the maintenance strategy as a strategic decision-making example, the thesis explores the feasibility of establishing a closed-loop maintenance logistics system for offshore wind farms. The life-cycle maintenance optimization problem is decomposed into a sequence of sub-optimization problems over multiple time periods using a rolling-horizon approach. Each sub-optimization problem is intentionally designed based on the monitored state of the wind farm and the available RAM database. Meanwhile, the decision-maker consciously mitigates the parameter uncertainty in the maintenance model gradually by updating the current database. The benefits of the proposed approach in decreasing revenue losses is revealed by comparing to the conventional approaches.

Mingxin Li

In September, Mingxin Li will compete against other European Thesis Award winners in Rimini during EuroMaintenance. The European award will be presented there by the EFNMS and Salvetti Foundation.

'How to improve effectiveness of maintenance strategies and resource organization for offshore wind farms and move towards a closed-loop decision-making approach'