Simulation and Optimisation of Offshore Renewable Energy Arrays for Minimal Life-Cycle Costs

R. Kuipers

Supervisors:
Kerem Akartunali
Euan Barlow

University of Strathclyde
Strathclyde Business School
Glasgow, Scotland

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Abstract

This report aims to give a detailed overview of the research progress I made between March 2018 and March 2019, the first year of this project. It will explain the research subject, give an overview of the relevant literature I've read and the limitations of the current research. Furthermore, it will discuss the work I've done on a simulator, to be used for later research. Finally, my future research on this topic will be estimated.

Contents

1 Introduction

Over the past year, I have been researching scheduling related to offshore windfarm projects; the installation, maintenance, and dismantling of windfarms in various seas, primarily the North Sea. The installation and dismantling projects can often take up to several years, and the lifespan of such farms is about 30 years, over which maintenance has to be done. For these projects, expensive vessels have to be used, the rent of which is often upwards of £100.000 per day [BTOD$^+$14a], hence a project with multiple vessels over many months can cost hundreds of millions of pounds. Therefore, even small improvements to the schedules can save significant amounts of money.

Because of that, I expected a lot of research in this area had already been conducted, but this turned out to be less the case than I would have expected. Most research is fairly recent, and there are significant literature gaps. The primary obstracle in this scheduling problem which seperates it from more traditional scheduling problems is the high degree of non-deterministic factors, mainly related to the weather conditions. These projects take place on open sea, where weather can often be rougher than on land. In addition, the high-tech vessels are performing operations on big industrial constructions, so they have a limited range of allowed wind speeds and wave heights. Something else which can further limit possible schedules is the inflexibility involved in vessel rental, since vessels of the required caliber cannot be rented on short notice, and often need to be rented for at least some minimum amount of time [KV17], so adaptive in-the-moment scheduling is impossible and we cannot simply wait for an expected period of good weather based on real-time data to rent the vessels; if we expected some period to have good weather but this turns out not to be the case, we'll often have the vessels rented but unusable. This means the problem has a lot of undeterministic yet impactful factors which any good solution would have to take into account.

In this report I will talk about my progress and what I have learned over the past year. First, in Section 2 I will explain the examined problem in more detail. After that, in Section 4, I will recount the reading I have done over so far, which was the main focus of my work over the past year. This will include both research on this specific project, and research in the more general fields of (stochastic) scheduling, optimisation and simulation. This will be the main focus of the report, as it was the main focus of my work. In addition to reading up on the state of the current research, I have also started building a Simulator for this problem, which I will discuss in Section 5. Finally, I will summarize my current standing and plans for future work in Section 6.

2 The project

In this section I will attempt to summarize the different views I've seen on the project, in enough detail for the reader to understand the rest of the report. I will primarily talk about installation projects, as most of the literature I've read is about those problems. It is likely the dismantling projects are very similar in structure; anything that was build needs to be taken apart. Maintenance projects however will be very different, as they are over a much larger time scale and while the two other types of projects have a set number of tasks that would ideally be completed as fast as possible, the mainenance has a set duration, with a potentially varying number of tasks.

A typical windfarm will have two types of structures: Wind Turbine Generators (WTGs) and Offshore Substation Platforms (OSPs). The WTGs are the actual turbines generating energy, and the OSPs are hubs where the power generated in the WTGs is gathered and transformed before being transported to shore. A typical windfarm might have upwards of 100 WTGs and 2 OSPs [BÖR+18]. Each of these structures has a set of tasks that need to be completed in series for each individual structure, like preparing the sea surface, laying the foundation, installing the structure and laying the cables (each of these tasks may be split into more tasks such as loading, transport and installation) [KV17]. Within the group of tasks for a structure, most tasks will have to be performed in a specific order, while the tasks for seperate structures can be completed in any order. This is essential for some of the more sophisticated objective functions used in the literature; if one OSP and a set of WTGs connected to it are active, they can start generating power while the rest of the wind farm is still under construction [BTOR+17]. This would mean the farm starts making money significantly earlier, and can therefore have big impacts on desired schedules. In some situations the company might even set desired deadline for certain milestones, like 10% or 50% of the turbines being operational.

The measure with which to compare schedules can vary. The most basic measure would be to produce a schedule with the earliest end time. Given the stochastic nature of the project, naively this would become the earliest expected end time. There are however a lot of different goals that could be described; instead of expected end time, a high confidence might be desired for the specific project. So instead of looking at the expected end time, one could for example look at the end time by which we can be 95% certain the project would be completed (based on simulations). Using the end time as a measure is also up for debate, as the net profit is often more important for the companies doing these projects. So while the end time would obviously be postponed, completely halting the project over the winter months (during which no rent would be payed for the vessels) might be beneficial for the total costs, since there will be less individual days during summer where the weather would require the work to be halted (while the vessels would still be rented). As I will be discussing a lot of the literature in Section 4 I will discuss the goals and objective functions in more detail there.

3 Methodology

In the literature, two main types of methods are used for this problem; optimization and simulation. Often both are used together, either by tackling one part of the problem with simulation and another with optimization (as in [BÖR+18]), or by creating schedules with an optimization model, which are then evaluated using simulation (as in [KV17]). Exactly how certain previous research uses these methods will be discussed more in Section 4, but a more general look at these methods, as well as other methods currently under consideration for this research, will be given in this section.

3.1 Simulation

Simulation, especially Discrete Event Simulation, is a good method to evaluate the strength of a proposed schedule under uncertain circumstances. If enough simulations are run, an accurate view of the realistic duration of a schedule can be gained. This does not only mean expected (average) duration, but also for example a confidence interval for the extreme cases. This does however have two big bottlenecks; the information gained through simulation can only be as precise as the weather model used for it, and doing enough simulations can take considerable time.

If the weather data is limited in precision or amount of data available, the results of the simulation in turn will also be limited. First of all is the precision of the data; a simulation as detailed as we would like for this type of project would have timesteps in the range of 15 minutes to an hour. A lot of weather data has much larger timesteps, often of several hours. There are methods to interpolate between weather data points, but this tends to not be very precise as there are a lot of factors to take into account. The most important measures of the weather are wind speed and wave height, as by these measures the usability of the vessels can be determined. In order to have this data be realistic, the two measures have to be correlated, as well as have autocorrelation over time (the weather does not often drastically change in the span of 15 minutes). Having those values be realistically interpolated between two measured points is a difficult task, and something we will have to figure out a way to realistically handle for future research.

The amount of data available is also a common problem. A major reason for this is the natural change of weather depending on the time of year. Generally, a year would be split up in sections, for example the four seasons or the twelve months. Intuitively this makes a lot of sense; if we want to model the weather in January data from July is irrelevant for this. But the consequence of this is the shear time it takes to collect accurate data for each time period; if we want 300 days of data for the month of April, we need data collected over the span of 10 years. In addition, the conditions of the location the data is gathered from have to be similar to the location of the windfarm. The most important parameter for this is the distance to the shore, but there are more factors which play a part.

A method to handle these drawbacks of the weather data is to not use raw data, but analyze the periodic characteristics of the change of both wind and wave states. Using these characteristics, one can generate weather data by drawing a random real data point within the desired time period, and extrapolating the data from there using the found characteristics. This is something we are planning to explore in future research, and we think it has potential to give a good weather model to be used for stochastic simulations.

Another method we are considering to explore relates more to robust optimization. It might not be necessary to have a large number of simulations for all possible weather conditions. If, for each time period, we create a range of possible wind and wave states (including the extreme cases from the data) and run simulations for each (realistic) combination of them we could aim to make a robust schedule that performs well within even the most extreme weather scenarios without having too many simulations to run (if the durations of tasks are deterministic a single simulation for each weather state would be enough). The drawback of this robust approach is a schedule that performs well in 99% of weather cases might be discarded for the most extreme 1% of cases. This can however be reduced by carefully selecting the data to use for the simulations, or allowing a certain number of bad scenarios (especially if the weather causing it is very rare). We might explore this more in future research.

3.2 Optimization

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3.3 Other Methods

Lorem Ipsum

4 Literature

In this section I will discuss a selection of the literature I have read so far for my research. In all the literature I discuss I will discuss the methods, assumptions, goals and results of each work. I have separated it into several subsections, depending on how closely related to my topic the discussed research is, as much more general scheduling methods will also be discussed to some extend.

4.1 Schedulling the installation

Lorem Ipsum
[BÖR+18]
[KV17]
[BTOR+17]

4.2 Related research regarding offshore projects

Lorem Ipsum
[BTOD+14b]
[BTOD+14a]
[LSAM18]

4.3 More general work on stocahstic scheduling

Lorem Ipsum
[HL05]
[SS02]
[AR00]

5 Simulator

Lorem Ipsum

6 Future Work

Lorem Ipsum

References

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