White paper:

Accurately forecasting O&M costs

Romax INSIGHT

Accurately forecasting O&M costs

O&M costs for wind farms are generally difficult to predict and can vary significantly between wind farms and turbine technologies. This white paper explains some of the reasons why accurate O&M cost forecasts are important, along with some of the approaches that Romax InSight employs to estimate future failure rates and costs.

O&M cost is by far the least predictable factor in a wind farm's OPEX and the industry is demanding more accurate predictions. The main drivers are:

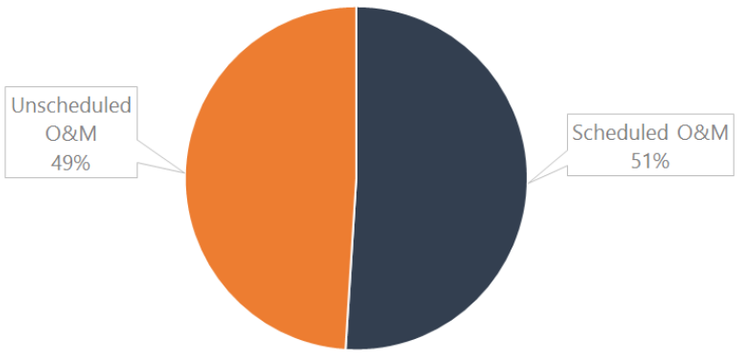
- Investors need certainty. Typically, the business plan has to be viable with 90% or 99% certainty (referred to as the P90 and P99 cases respectively).
- If an equity investor's business plan has greater certainty, the cost of borrowing can reduce.
- Lenders are more willing to fund a project if uncertainty can be minimised. Relatively speaking, the lender is less exposed to risk compared to an equity investor but needs to see certainty in the availability forecast and wishes to quantify the impact of major component failures on availability.

What drives uncertainty in O&M cost?

Wind farm O&M cost is primarily made up of scheduled (planned) and unscheduled (unplanned) maintenance. Scheduled maintenance is generally easy to predict, especially for an operational wind farm with existing maintenance contracts in place. The main source of uncertainty is unscheduled maintenance, and the biggest driver behind this is what we call *technology risk*.

The wind industry moves quickly with respect to technology development so technology risk is inherent in any project. Whether it is a new turbine type that is relatively unproven, an existing turbine type with a new gearbox variant, blades from a new supplier or a new control algorithm that has been rolled out by the OEM. These are just a few examples that may introduce the risk of more unplanned maintenance – or at the very least, an increase in the P90-to-P50 ratio (i.e. a wider standard deviation in the likely O&M costs).

Example onshore wind farm O&M cost distribution
[source: Romax InSight database]

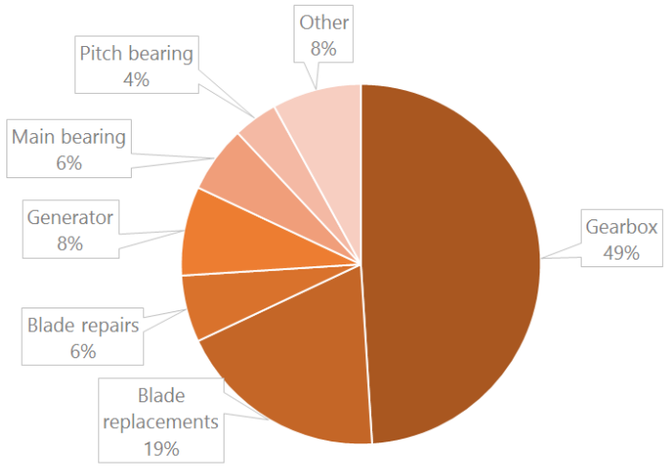


Uncertainty in O&M cost is not the only problem. A machine failure will also impact availability, which in turn can mean that revenue targets are not met. In territories such as the USA, this can have knock-on effects for tax equity investors. In Europe, availability loss due to failure is often magnified as many turbines are offshore with constraints due to vessel availability, tides and weather. The impact of technology risk and uncertainty are wide ranging.

The approach to O&M cost forecasting

To overcome potentially runaway unplanned O&M costs and the lack of certainty, investors use experts such as Romax InSight to construct accurate O&M cost forecasts, including detailed predictions of uncertainly. Romax InSight's approach is to combine site-specific information from the wind farm, plus turbine-specific and technology-specific information from a vast historical database of past information. The figure on the following page shows various types of data used in the O&M cost forecast.

Example breakdown of unscheduled O&M costs
[source: Romax InSight database]



The accuracy of an O&M cost forecast is clearly critical to meeting the long term financial goals for a project and is therefore very important. Some solutions for avoiding common pitfalls include:

1. **Utilise historical failure data.** By keeping turbine information and reliability data in a large database, failure statistics can be quickly constructed for any turbine type, right down to subcomponent level. For example, historical data will tell us if gearbox revision E has a better or worse failure rate than version D – and therefore the impact on future unplanned O&M costs. Naturally, some turbine data will be qualitative and may require interpretation by an engineer, while other data will be quantitative and can be fed directly into statistical models.

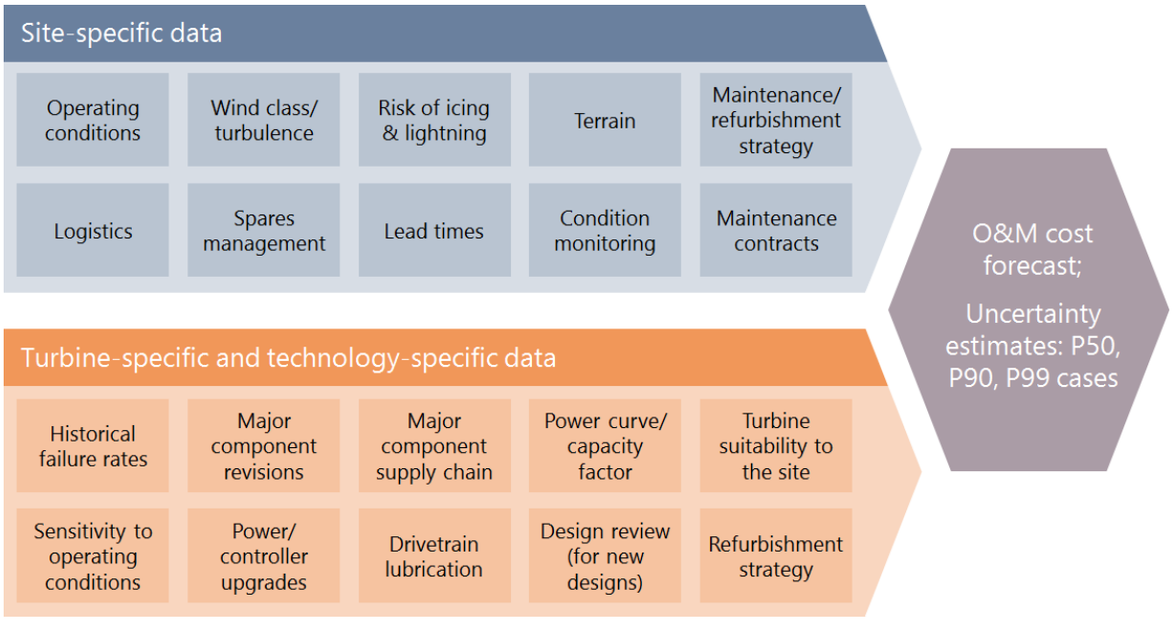
2. **The forecast must be site-specific.** No two wind farms are the same. Factors such as turbulence, terrain, proximity to ridges or forests, the risk of icing or lightning and the suitability of the turbine to the site all play a part in O&M cost predictions.

3. **Logistics matter.** If a site is located a long way from other wind farms, the lead time for large cranes can be very long and the costs for mobilising a crane can be high. This matters a lot, because the crane cost is usually a significant part of the repair cost for a major component. Lost production cost can be high while the site waits for a crane and spare parts to arrive. A predictive maintenance strategy, led by CMS, can have big benefits in situations like this – particularly when a turbine can continue to run with a known fault whilst being monitored closely.

4. **The is no substitute for experience.** Talk to the site managers; read operational reports; interview technicians. People on site almost always know which turbines are problematic, even if they might not have the relevant expertise to diagnose the problem.

5. **Evaluate your supply chain.** Some turbine OEMs have gone out of business, been bought up and their turbine models made obsolete. Even large and stable OEMs often decide to reduce support/increase price on parts for older models. A robust third party supply chain for parts, engineering, monitoring and O&M services mitigates risk.

6. **Predictive maintenance matters.** Analysis has shown that moving to predictive or planned maintenance rather than a reactive strategy can potentially save up to 40% in O&M costs. In practice, this can be delivered through better use of condition monitoring, particularly for older/smaller machines with no CMS, predictive tools such as component life models, along with better management of data relating to reliability, inspection and servicing using software such as Fleet Monitor and Field Pro.

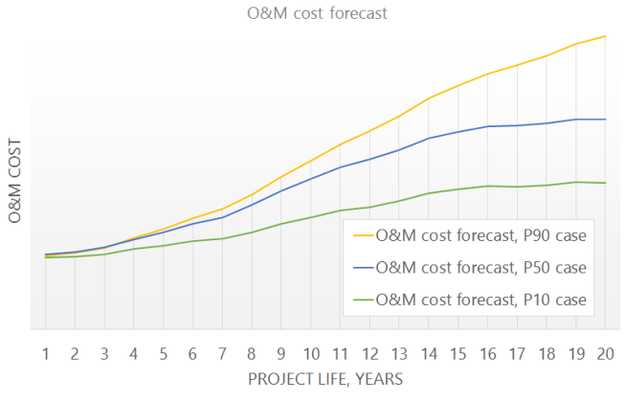


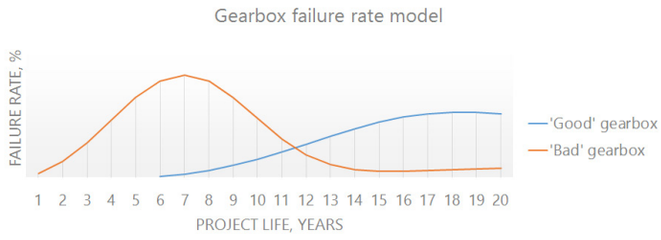
Input data for Romax InSight's O&M cost model

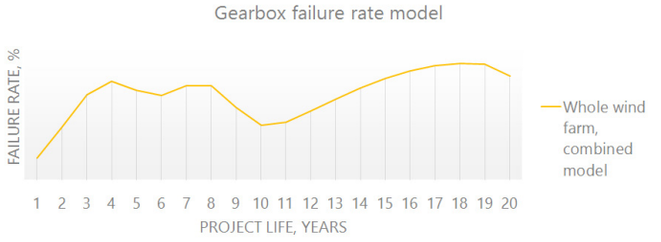
A statistical prediction

The process for predicting O&M costs is complicated and uses a statistical approach, with Weibull curves describing the failure rates of major components. Simulations are run to estimate failure rates for the whole wind farm, from which O&M costs are calculated and multiple scenarios are evaluated, e.g. P50, P90 and P10 cases.

The graph opposite shows an example O&M cost forecast, with alternative scenarios evaluated to help inform the investor's decision. Many layers of detailed analysis and breakdowns of costs are provided during a project. For this site there is a wide spread between the P90 and P50 cases, with a P90/P50 ratio that increases from 1.1 in year 10 to 1.5 in year 20. It is quite typical to see the uncertainty increase in the later part of a turbine's life, although the spread of predictions in year 20 is relatively high in this case, driven by a series of reliability problems for this turbine.







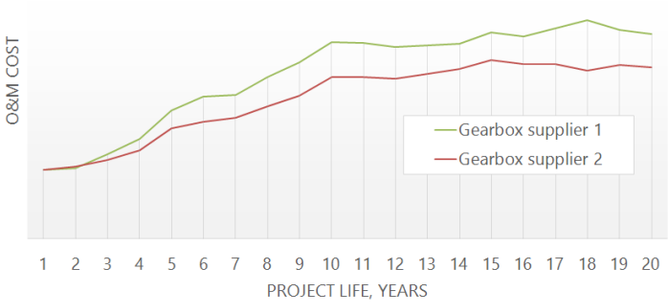
Drilling down deeper into this model, every major component is represented by a unique failure rate model, defined using historical failure data combined with 'turbine specific' and 'site specific' factors, as discussed above. However, not all major components are identical – for example, a wind farm can have gearboxes from different suppliers and with different bearing arrangements, each with very different failure rates. The graph opposite shows the failure rates for two different gearboxes on a wind farm where Romax InSight was performing due diligence for an equity investor. The 'good' gearbox in this model starts suffering end-of-life failures which peak around year 18, whereas the 'bad' gearbox suffers premature failures peaking in year 7.

A statistical prediction – continued

When these models are combined – bearing in mind that gearboxes get replaced at various points throughout the 20 year project – the resulting curve is shown in yellow in the previous graph. This 'combined' failure rate then feeds into a cost model, including all aspects of repair and refurbishment costs and taking into account cases of uptower repair and complete gearbox exchange.

For an investor, a model with this level of detail allows many scenarios to be run. For example:

O&M cost forecast for alternative gearbox suppliers



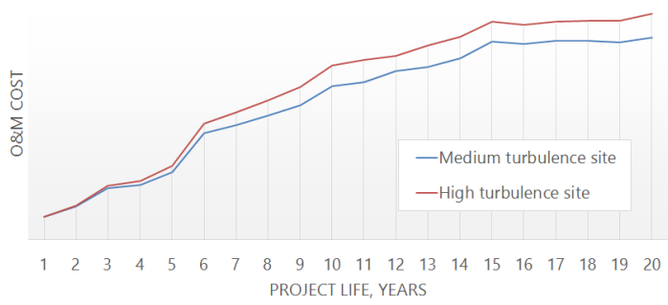
- What if I run a programme to exchange all my 'bad' gearboxes?
- What if I switch gearbox supplier? (See example opposite)
- After a gearbox failure, what is the benefit of installing upgraded refurbished gearboxes as opposed to a like-for-like swap?
- Should I pre-emptively swap out aging gearboxes with one crane operation or call out a crane reactively for each gearbox failure?
- How will these gearbox failures affect availability?
- If I install CMS on the drivetrain, what is the potential cost saving vs. cost of hardware and monitoring?

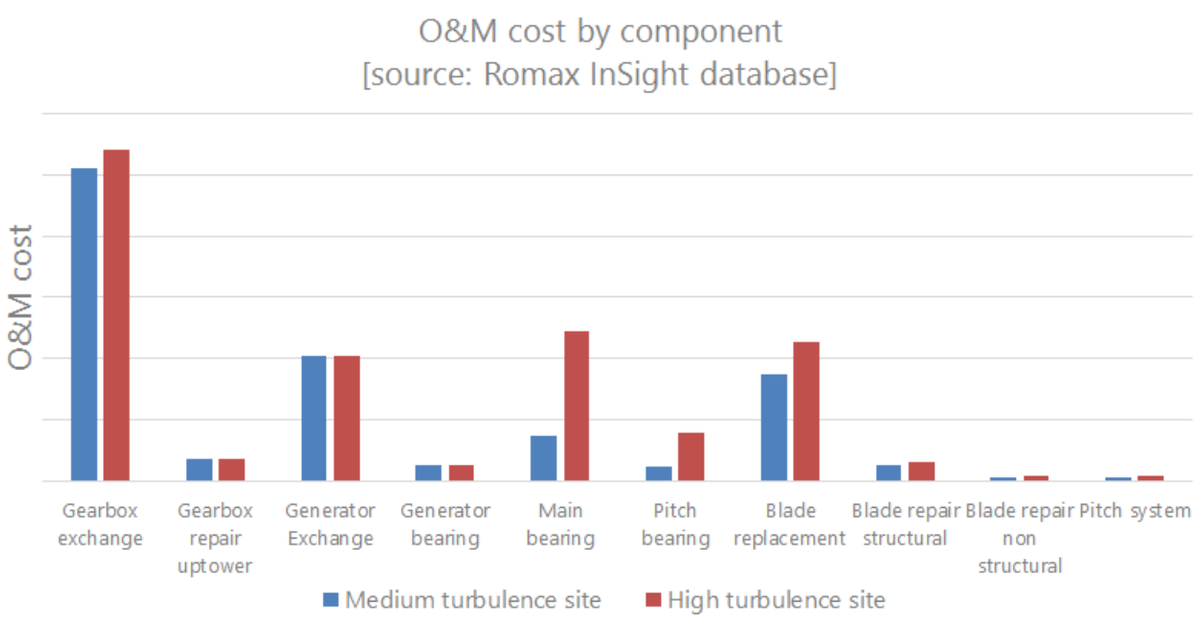
The impact of maintenance and location

Not all wind farms are maintained in the same way. It is unusual to see a site in India or China maintained to the same standard as a site in North America or Europe. The O&M cost forecast is a good tool for allowing an investor to compare sites within a portfolio or to evaluate different ISPs or maintenance strategies. Saving money on a lower cost service agreement may be tempting, but it is essential to model out the failure rates and potential future costs before making this decision. One analysis showed that that the annual O&M cost can increase by around 40% by reducing the maintenance quality – for example, running components to failure, missing service intervals, employing inexperienced technicians and using low quality components and consumables.

A significant 'site specific' factor affecting O&M costs is turbulence. It is common to see higher failure rates for main bearings, blades and pitch bearings due to increased turbulence. Also for 'three point mounted' drivetrains (with a single main bearing), gearboxes can see increased loading on planet carrier bearings and low speed stages. Consequently, it is common to see higher O&M costs for turbulent sites. The graph opposite shows a like-for-like analysis of two wind farms with the same turbine technology but varying levels of turbulence. Breaking down the costs in more detail reveals which turbine components are responsible for the increased O&M cost for the turbulent site. This type of analysis is extremely valuable when negotiating inclusions and exclusions in a service agreement or extended warranty.

O&M forecast showing impact of turbulence



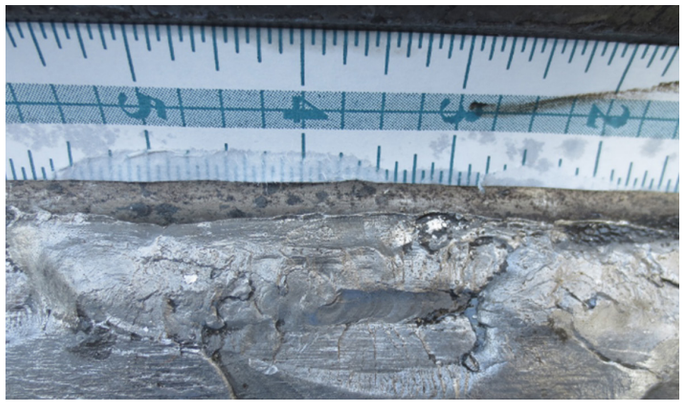


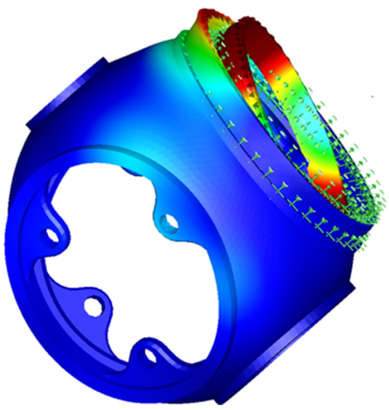
The nightmare scenario – a serial defect

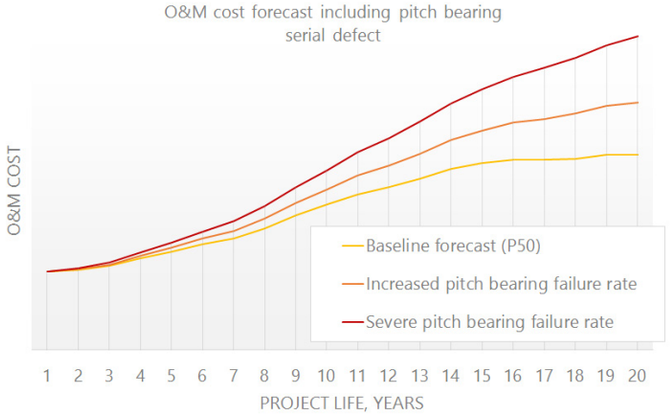
An investor's worst nightmare is that they close a deal on a wind farm, only for the turbines to start failing – and not just one-off failures, but a serial defect in a major component that appears to affect all the turbines. The potential costs can reduce the project net revenues to a point where the debt may not be fully covered.

Take for example pitch bearing failures, currently a widespread issue for the industry. A wind turbine has three pitch bearings supporting the blades. The image opposite shows a pitch bearing that failed prematurely due to excessive flexibility of the raceway, resulting in edge-loading on the bearing and a phenomenon known as ellipse truncation. This was confirmed using a RomaxWIND simulation including the deformation of the hub and pitch bearing, also shown opposite. The cost impact of a pitch bearing failure is huge – the repair requires a large crane operation, extensive downtime and three expensive replacement bearings.

Often, serial defects are well known within the wind energy community, with historical failure data available in the Romax InSight database, and can be identified early the investment process by doing a thorough review of the turbine technology. In this case, the potential impact of serial defects can be built into the O&M cost forecast and various scenarios modelled. The example opposite shows a study where the pitch bearing failure rate was varied depending on the expected severity of the serial defect. It is clear that the cost impact of this failure mode could ruin the business case for operating these assets, with the O&M cost in the most severe case around 60% higher than the baseline case. This would easily consume the cash reserve in a typical project.







What next?

The current state of the art for O&M cost and OPEX forecasting varies greatly. Once an investor receives an O&M cost forecast from an independent engineer such as Romax InSight, they have several opportunities:

1. **Compare forecasts.** It is always wise to compare the independent engineer's O&M cost forecast to the seller's forecast. In most cases, the forecasts will be in close agreement but occasionally there will be differences. It is vital that any differences are investigated quickly as they can reveal information that was not revealed by the seller, or possibly a potential serial defect that has been identified by the independent engineer but has not become obviously apparent on the wind farm yet.

2. **Use the forecast regularly.** Having an accurate O&M cost forecast is one part of the story, but what can the owner of the wind farm do with this information? One answer is to keep the forecast as a live tool which is updated at least once per year to aid with budgeting and planning. After 12 months, actual O&M cost data should be compared to the original forecast and the future forecast should be updated based on new information from the site. In most cases, the actuals and the prediction should be in close agreement.

3. **Improve the availability prediction.** Generally speaking, there is still great scope for improving the due diligence process. Investors and due diligence providers typically construct an availability forecast alongside the O&M cost forecast, but often there is little or no link between the two. In reality, these are interrelated and need to be modelled as such – if a major component fails and requires a large crane operation, there will inevitably be some downtime and lost availability. Without connecting the O&M cost and availability models, the investor risks over estimating availability and running into future problems when the wind farm doesn't generate as much revenue as expected.

4. **Drive cost reduction.** Most importantly, a new wind farm owner should use the O&M cost forecast to look for opportunities to reduce costs going forward. This could include installing CMS or making better use of existing CMS – in fact it is common to see CMS installed on a wind farm but never used, or in many cases used poorly. The owner may be able to make cost savings by switching to a different type of service agreement or moving away from the OEM to an ISP or hybrid O&M strategy, depending on their appetite for risk. The O&M cost forecast might also indicate that the owner should look at their spare parts and refurbishment strategy, with potential cost savings through better management of inventory or refurbishment suppliers. Historically, owners have replaced failed components such as gearboxes with like-for-like parts, but there is an increasing demand to extend life and reduce O&M cost by retrofitting upgraded components. An accurate O&M cost forecast is an extremely powerful tool to enable this type of business decision.

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