Beyond Belief: Extending the life of Offshore Wind Farms using Bayesian Belief Networks

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H R Mitchell, N Pready, P Thies, D Garcia Cava, A Mehmanparast

Frazer-Nash Consultancy

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Introduction

- Approximately 400 WTs in UK waters will reach the end of their design life (20-25 years) by 2030 [2]
- Lifetime extension of WTs is becoming more important, however, it has not yet been demonstrated in an offshore setting
- There is a lot of uncertainty in the design, operation, and condition of offshore wind turbines. But, Probabilistic Bayesian methods cope well with uncertainties
- The aim of this project is identify if we can apply Bayesian methods to determine the remaining useful life of offshore wind turbines

OK

It looks like you're trying to understand Bayes' Theorem

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

The posterior probability of P(A|B) expresses the conditional probability of event A given the observation of event B [1].

When new evidence becomes available, the belief related to the outcome of a system has to change!

Bayesian BELIEF Networks

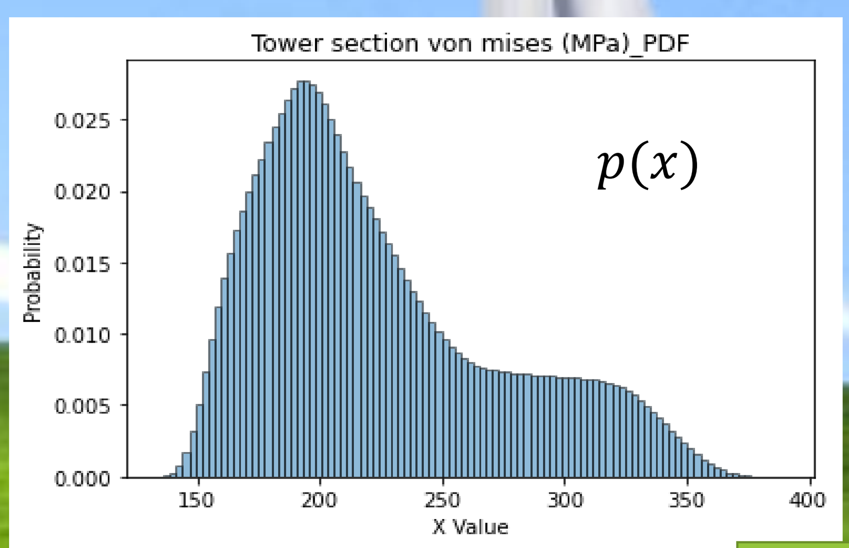
1. Create initial BBN of critical WT structural components as per design codes

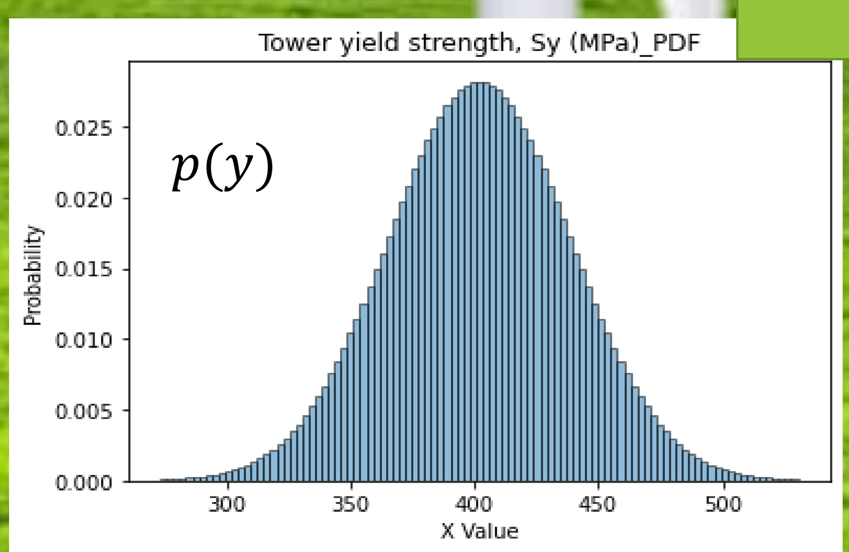
Example of BBN network taken from tower section

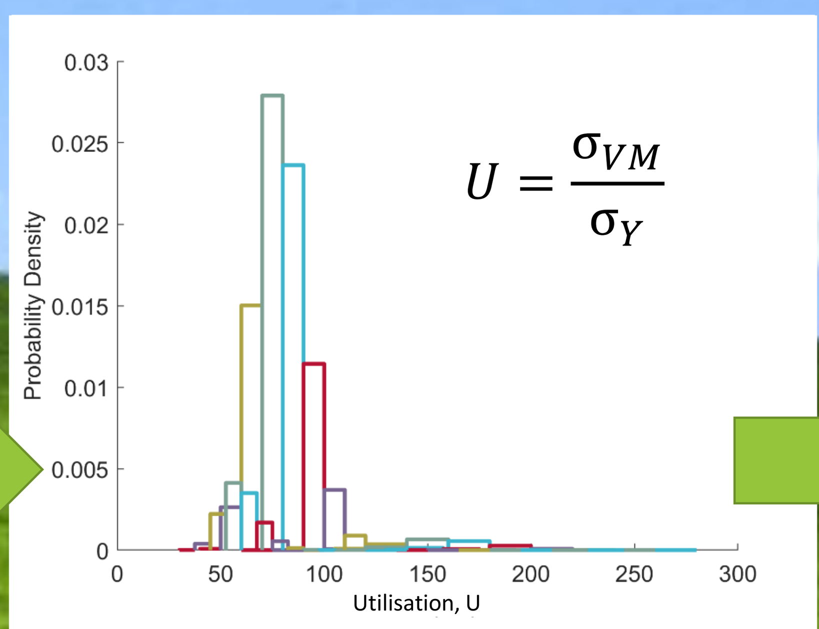
- Tower Loads, $M_{x,y,z}$, $F_{x,y,z}$
- Tower Geometry, t, D
- Von Mises Stress, σ_{VM}
- Material yield, $\sigma y * f_m$
- Extreme Utilisation, U

Note: The boxes in the BBN above are coloured by Sobol Indices. Green boxes show the input distributions that have the greatest affect on the output variance

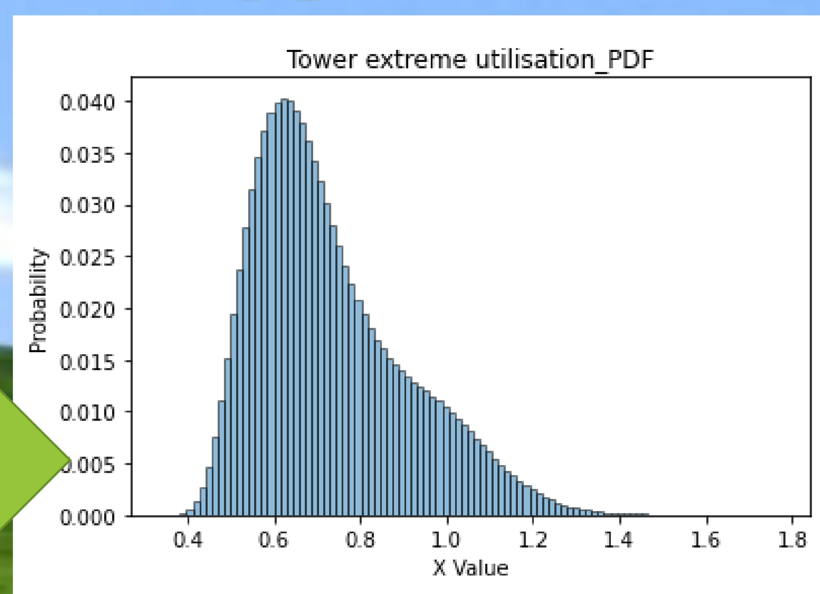
Direct Integration Approach







Divide each bar of distribution x (σ_{VM}) by distribution y (σ_y) to get new (overlapping) bars.



New bins are then created and contributions within each bin are added to get new distribution, z: z = f(x,y)

$$p(z) = \int p(z|x,y)p(x)p(y)dxdy$$

- Probability distributions are assigned to source nodes.
- Dependencies are mapped using mechanical equations
- Forward solve using direct integration approach
- Direct integration approach is an alternative to random sampling which is more time consuming and might not always cover full the range of inputs
- The direct integration approach is suitable as the network is made-up so that there are only two inputs to each node

Sobol Method

- Variance-based sensitivity analysis can be used to determine which inputs have the greatest impact on the total variation
- z can be broken down into its constituents:

$$z = f_0 + f_1(x) + f_2(y) + f_3(x,y)$$
$$f_0 = E(z), f_1(x) = E(z|x), f_2(y) = E(z|y),$$
$$f_3(x,y) = E(z|x,y) - f_0 - f_1 - f_2$$

- Total variance in z can be written as:

$$Var(z) = V_z = V_1 + V_2 + V_3$$
$$V_1 = Var_x\left(E_y(z|x)\right), V_2 = Var_y\left(E_x(z|y)\right), V_3 = V_z - V_1 - V_2$$

- So that the first order Sobol indices are:

$$S_x = \frac{V_1}{V_z}; S_y = \frac{V_2}{V_z}$$

Conclusion

- The full design network will be modelled and solved forward to show which input distributions have the greatest influence on the overall design life of the wind turbine.
- Next stage: to develop a dynamic network which will use operational data to update prior beliefs

Me

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References

[1] Adedipe Tosin, Mahmood Shafiee and Enrico Zio (May 2020). Bayesian Network Modelling for the Wind Energy Industry: An Overview, Reliability Engineering and System Safety 202 (2020). DOI: 0.1016/j.ress.2020.107053

[2] Spyroudi, Angeliki (April 2021). End-of-Life Planning in Offshore Wind.

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Scottish Association for Marine Science — The University of Edinburgh — University of Strathclyde Glasgow — University of Exeter — UKRI Natural Environment Research Council — UKRI Engineering and Physical Sciences Research Council

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