



TECHNOLOGY & INNOVATION CENTRE

Cost Benefit Analysis of Mothership Concept and Investigation of Optimum Operational Practice for Offshore Wind Farms

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Presentation Outline

- Problem Identification
- Potential Solutions
- StrathOW-OM Methodology and Tool Interface
- Case Study
- Results
- Conclusion
- Future Work



Problem Identification

New Generation Offshore Wind Farms

- Moving far offshore (>50 nautical miles)
- Occupying larger area
- Very long transit time
- Limited actual productive time
- Long reaction time to failures
- Increasing downtimes
- Very high O&M/MWh costs

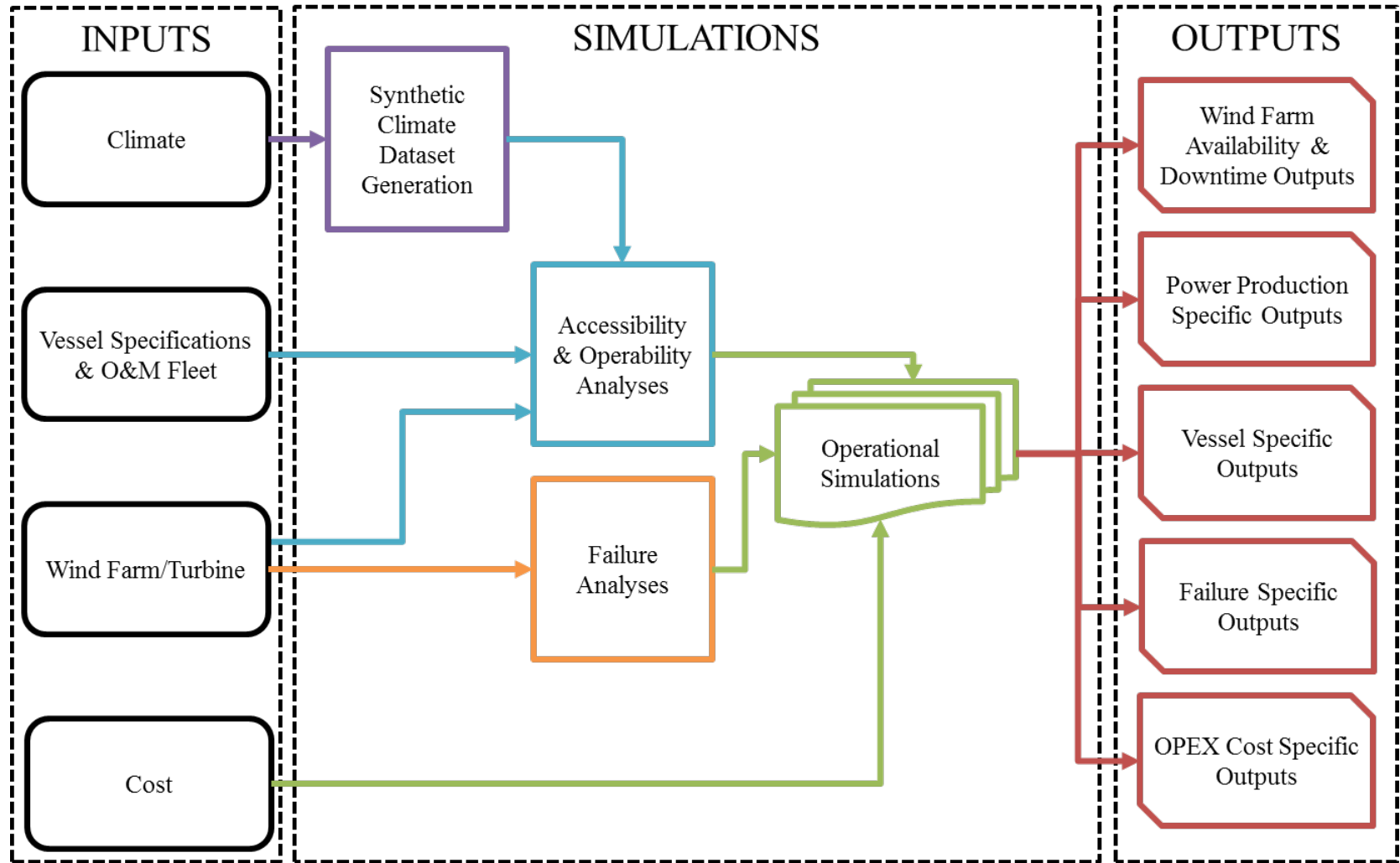


Potential Solutions

- Design and build advanced vessels
- Increase the size of O&M fleets
- Build O&M ports on islands
- Install a fixed offshore platform
- Purchase/charter a mothership
- Cancel the projects



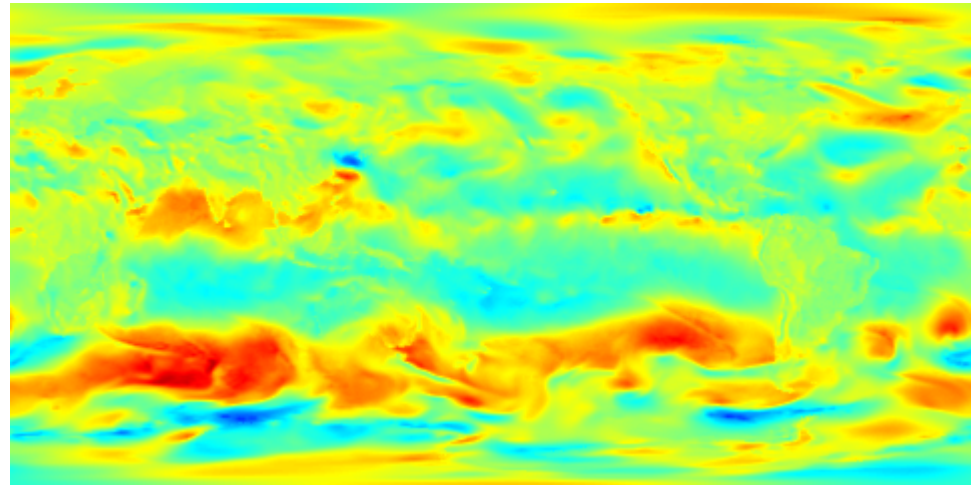
StrathOW-OM Methodology



Methodology

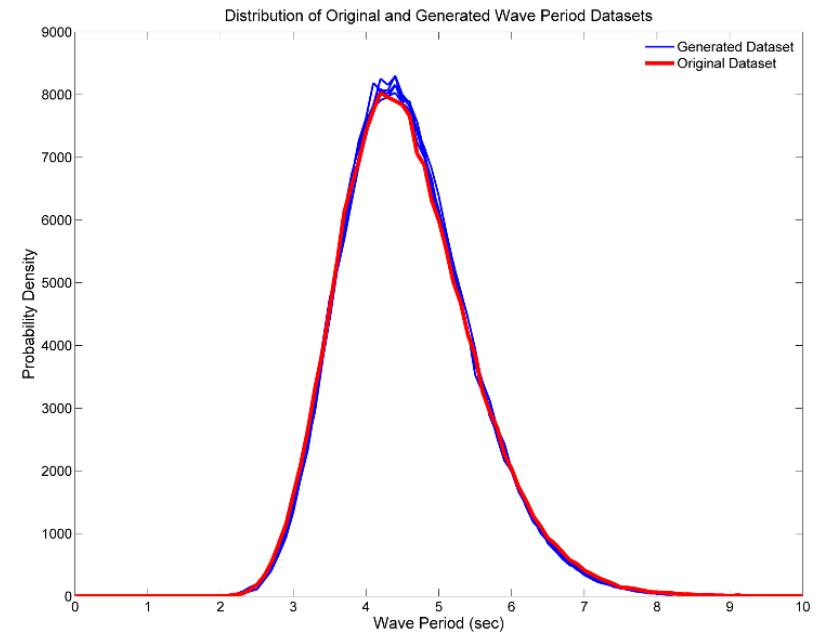
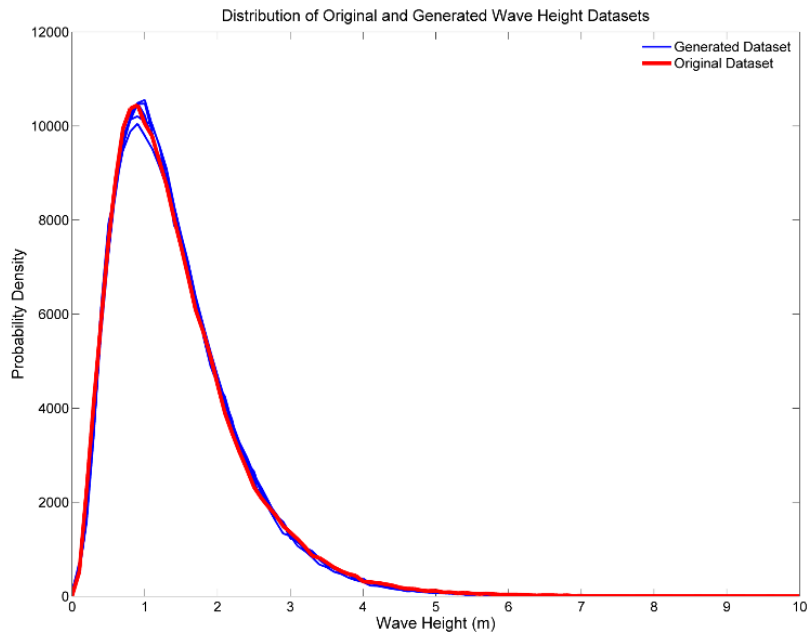
- Climate Dataset Generation

- Analyse Meteorological time series.
- Remove deterministic seasonal and diurnal trends in climate data
- Estimate distributions of climate data.
- Sample from the distributions
- Re-apply deterministic trends



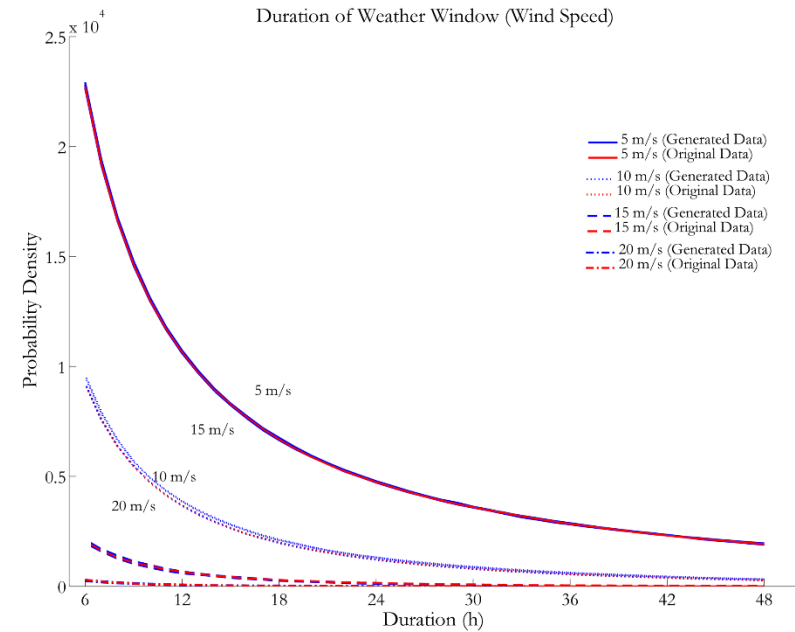
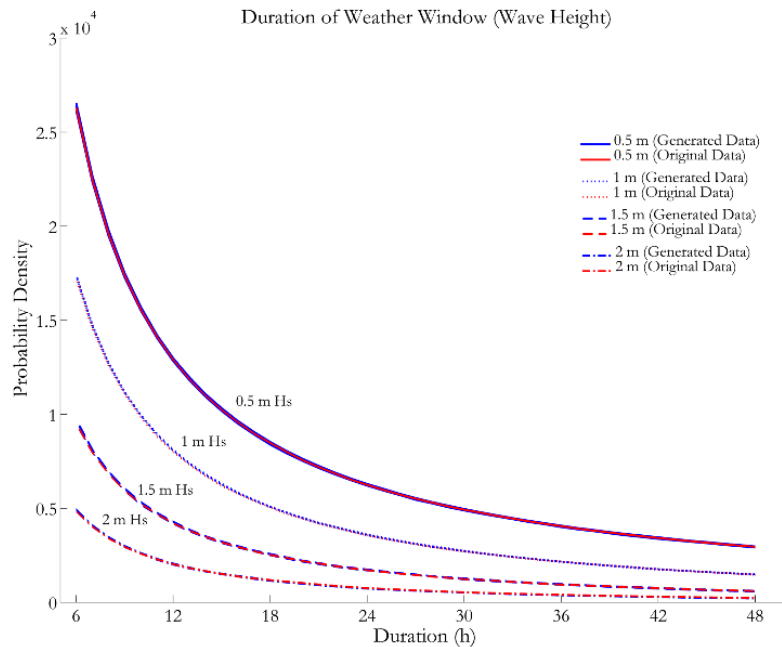
Methodology

■ Climate Dataset Generation

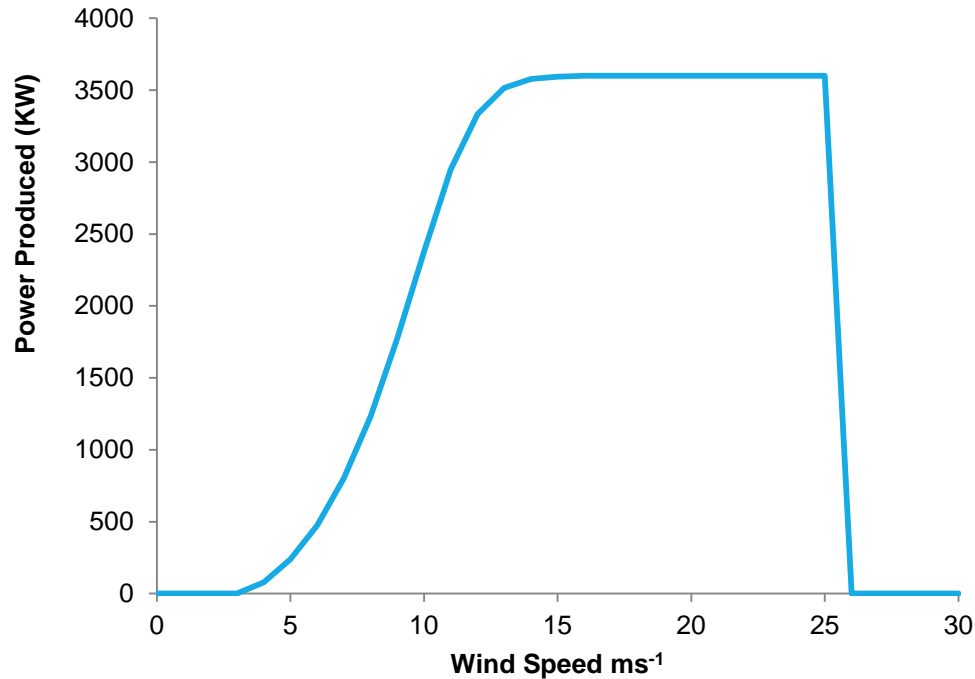


Methodology

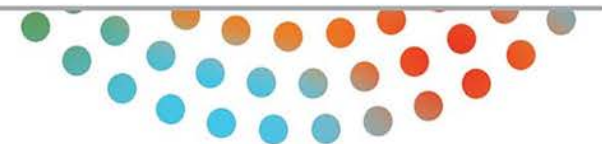
■ Climate Dataset Generation



Wind Turbine Behaviour



Failure Type
Required Repair Time - Calender Hours
Required Technicians
Vessel Type
Cumulative or Single Repair Window
Global Failure
Percentage of wind farm production impacted (%) (0-100)
Percentage of turbine production impacted (%) (0-100)
Failure Model Type

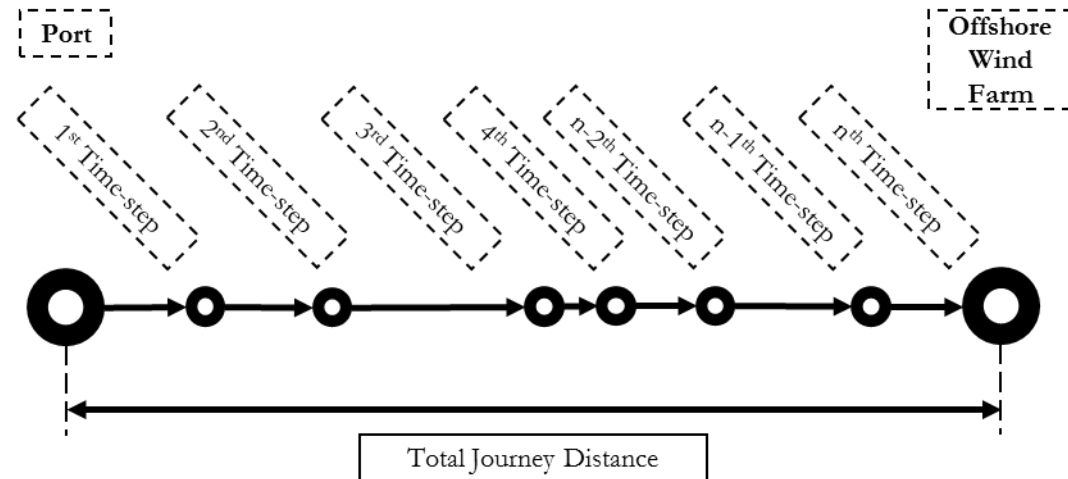


StrathOW-OM Methodology

- Accessibility and Operability
 - Calculation of total calm water resistance
 - Calculation of additional wave resistance
 - Calculation of total resistance
 - Calculation of speed loss in wavy sea
 - Calculation of transit time

$$Distance_i = Time\ Step\ Interval \times V_{Ai}$$

$$Total\ Distance = \sum_0^i Distance_i$$



StrathOW-OM Methodology

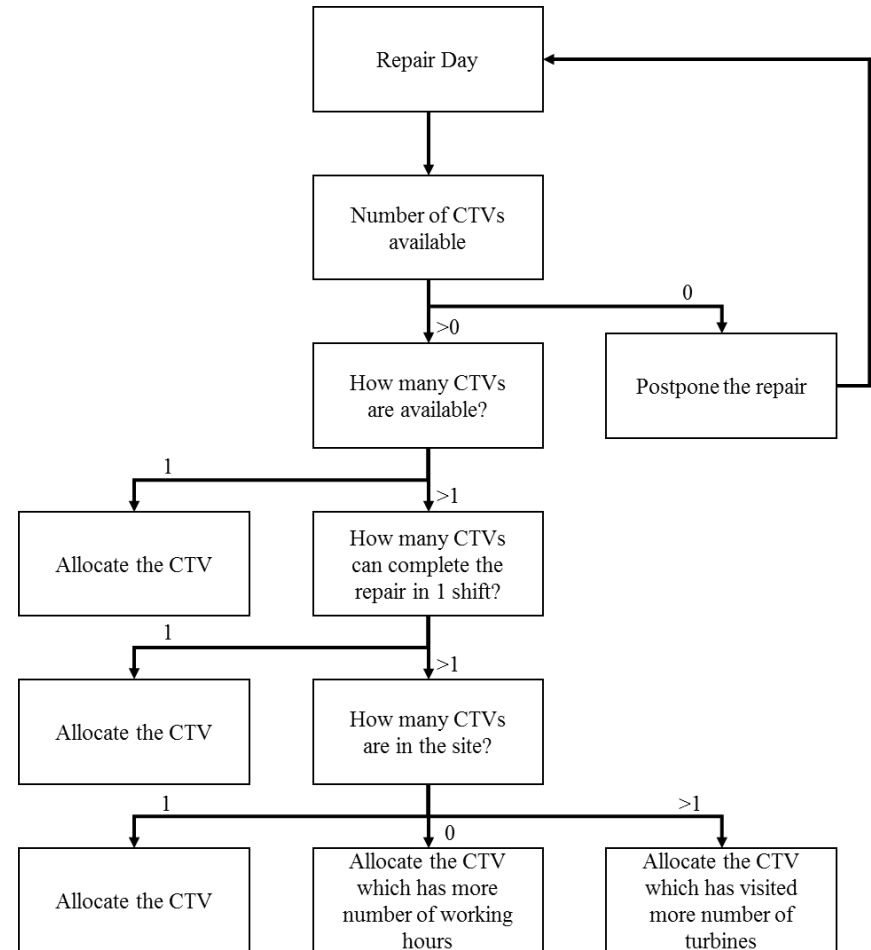
- Failure Analyses and Simulation

- Monte-Carlo Simulation

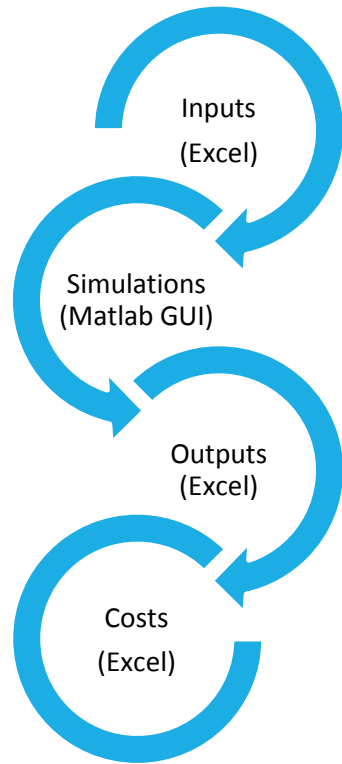
- Random Number Generation, R

- Hazard Rate $h(t)$

$$R > (1 - h(t)) \cdot \frac{\Delta t}{8760}$$



StrathOW-OM Tool Interface



Wind Farm Inputs				Vessel Inputs							
Number of Turbines				CTV		Helicopter		Mothership			
80				Vessel Type	Catamaran	Monohull	Catamaran	Helicopter Usage	Yes	Mothership Usage	Yes
Minimum Working Hour				Length (m)	18	24	32	Annual Helicopter Hours	500	Type	Specialised Vessel
2				Breadth (m)	2.1	2.5	3	Technician Capacity	6	Perform Maintenance	Yes
CTV Shift Start											
08:00											
Maximum Visit per CTV											
3											
Inter-transit time (min)											
20											
CTV Opt. - Limited by Daylight											
Yes											
CTV Tech. Maintenance Schedule											
Scheduled maint. after corrective maint.											
Arrival to Turbine - Work Start (min)											
0											
Tech. Pool (Day)				Multiplier							
36				1.5							
Tech. Pool (Night)				Multiplier							
18				2.5							

StrathOW-OM GUI

Run Simulations

Define Sensitivity Studies

CTV Opt.

Jack-up

Fail Rate

Run Sensitivity

About

University of Strathclyde Glasgow

Process status - updates during batch run

Year	MEAN or Total	1	2
Availability - Turbine based	94.10%	93.95%	93.48%
Availability - No scheduled maintenance	94.78%	94.63%	94.16%
Availability - OEM	97.48%	97.50%	97.48%
Availability - Power based	94.29%	94.16%	93.17%
Availability - Absolute	94.10%	93.95%	93.48%

Market Electricity Price (£/MWhr)	50.00	Lost Electricity Revenue	20.38 m	3.03	
Support Mechanism Value (£/MWhr)	45.00	Lost Support Mechanism Revenue	36.69 m	5.46	
Support Mechanism Ratio	2.00				
Power Exposed	Electricity Price (£/kWhr)	140	Lost Revenue	57.07 m	8.50
Lost Power					
Permanent Technician Cost (£/year)	60,000	Total Permanent Tech. Cost	65.34 m	9.73	
Temporary Technician Cost (£/year)	80,000	Total Temporary Tech. Cost	0.55 m	0.08	
CTV No					
CTV-1	Total Daily CTV Charter Payment (£)	16,000	CTV Hire Cost	64.24 m	9.56
CTV-2	CTV Fuel Cost (£/litre)	0.45	CTV Fuel	1.94 m	0.29
CTV-3	Fixed CTV Costs (£/year)	150,000	CTV Total	67.83 m	10.10
CTV-4					
CTV-5	Helicopter Fuel Cost (£/litre)	1.20	Heli Fuel Cost	2.64 m	0.39
CTV-6	Fixed Helicopter Cost (£/year)	1,000,000	Heli Total	13.64 m	2.03
CTV-7					
CTV-8	FSV Day Rate (£)	0	FSV Hire Cost	0.00 m	0.00
CTV-9	FSV Mobilisation Cost (£)	0	FSV Mob Cost	0.00 m	0.00
CTV-10	FSV Fuel Cost (£/hr)	0.00	FSV Fuel Cost	0.00 m	0.00
CTV-11	Fixed FSV Costs (£/year)	0	FSV Total	0.00 m	0.00
CTV-12					
CTV-13	Jack Up Day Rate (£)	80,000	Jack Up Hire Cost	67.50 m	10.05
CTV-14	Jack Up Mobilisation Cost (£)	500,000	Jack Up Mob Cost	7.90 m	1.18
CTV-15	Jack Up Fuel Cost (£/litre)	0.30	Jack Up Fuel Cost	0.06 m	0.01
	Fixed Jack Up Costs (£/year)	0	Jack Up Total	75.46 m	11.24
	Mothership Day Rate (£)	10,000	Mothership Hire Cost	13.53 m	2.01
	Mothership Mobilisation Cost (£)	0	Mothership Mob Cost	0.00 m	0.00
	Mothership Fuel Cost (£/litre)	0.00	Mothership Fuel Cost	0.00 m	0.00
	Fixed Mothership Costs (£/year)	2,000,000	Mothership Total	35.53 m	5.29

Case Study

- A fixed accommodation platform concept (A)
- A floating hotel mothership concept (B)
- A pro-active mothership concept (C)

(A)



(B)



(C)

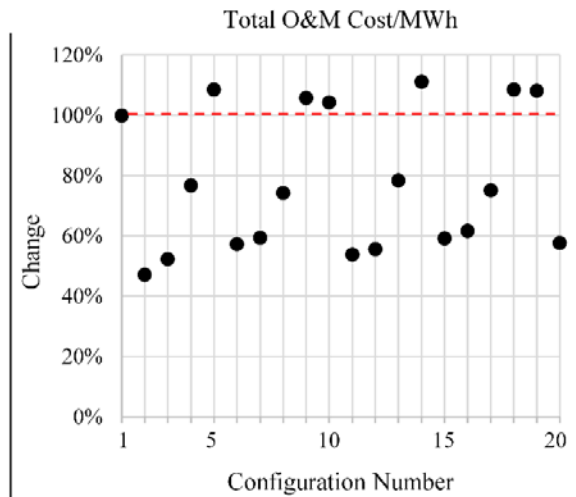
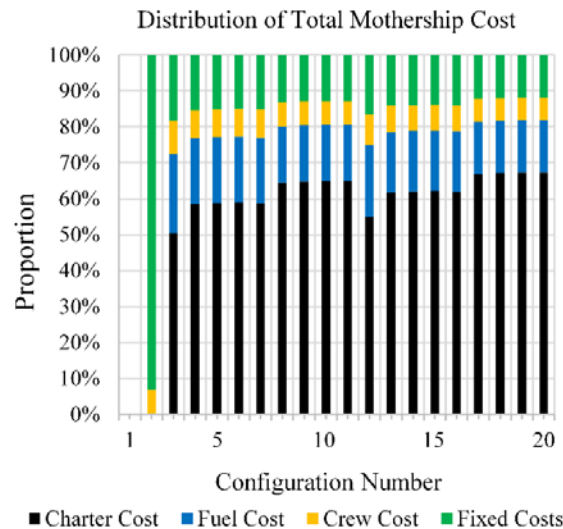
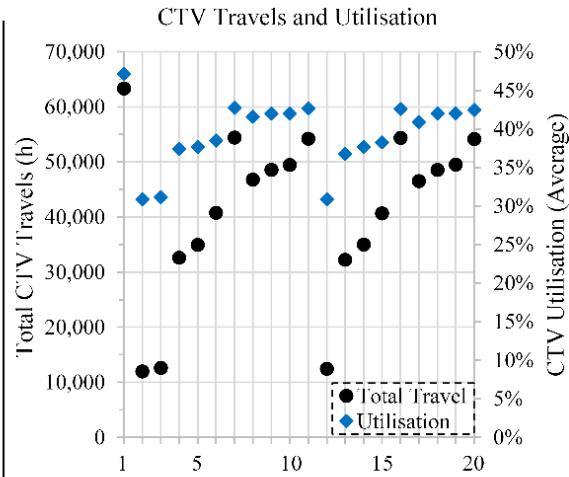
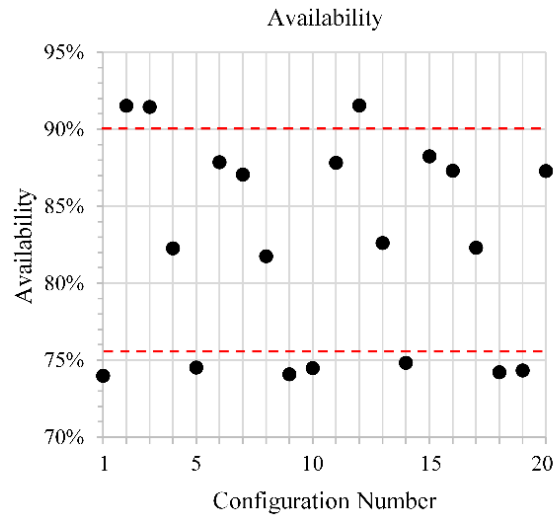


Case Study

No	Configuration	Charter Type	Start Month	Final Month	Period	Daughter craft	No	Configuration	Charter Type	Start Month	Final Month	Period	Daughter craft
1	No mothership	N/A	N/A	N/A	N/A	N/A	-	-	-	-	-	-	-
2	Fixed platform	N/A	N/A	N/A	25 years	N/A	-	-	-	-	-	-	-
3	With mothership	Continuous	N/A	N/A	25 years	N/A	12	With mothership	Continuous	N/A	N/A	25 years	3
4	With mothership	Seasonal	Jan	Jun	6 months	N/A	13	With mothership	Seasonal	Jan	Jun	6 months	3
5	With mothership	Seasonal	Apr	Sep	6 months	N/A	14	With mothership	Seasonal	Apr	Sep	6 months	3
6	With mothership	Seasonal	Jul	Dec	6 months	N/A	15	With mothership	Seasonal	Jul	Dec	6 months	3
7	With mothership	Seasonal	Oct	Mar	6 months	N/A	16	With mothership	Seasonal	Oct	Mar	6 months	3
8	With mothership	Seasonal	Jan	Mar	3 months	N/A	17	With mothership	Seasonal	Jan	Mar	3 months	3
9	With mothership	Seasonal	Apr	Jun	3 months	N/A	18	With mothership	Seasonal	Apr	Jun	3 months	3
10	With mothership	Seasonal	Jul	Sep	3 months	N/A	19	With mothership	Seasonal	Jul	Sep	3 months	3
11	With mothership	Seasonal	Oct	Dec	3 months	N/A	20	With mothership	Seasonal	Oct	Dec	3 months	3



Results



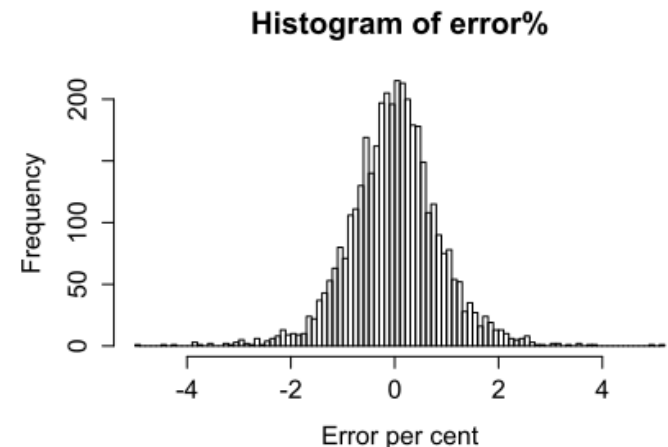
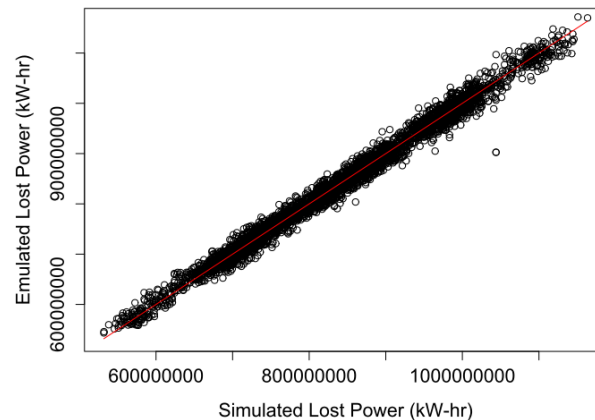
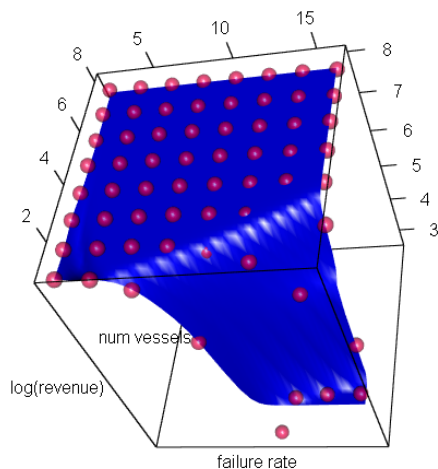
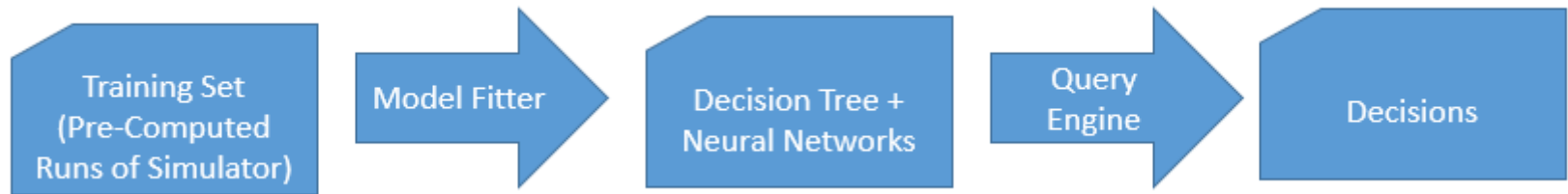
Emulator

- Monte-Carlo convergence requires hundreds to thousands of runs of the simulator, which can take several hours.
- In order to allow quick decisions and automated optimisation, we need a continuous function approximation of the simulator's response.
- Hence we have developed such a model. We call it the “emulator” of the simulator.
- Emulator does not try to represent the internal state of the real world phenomenon, and instead tries to replicate the input-output behaviour.

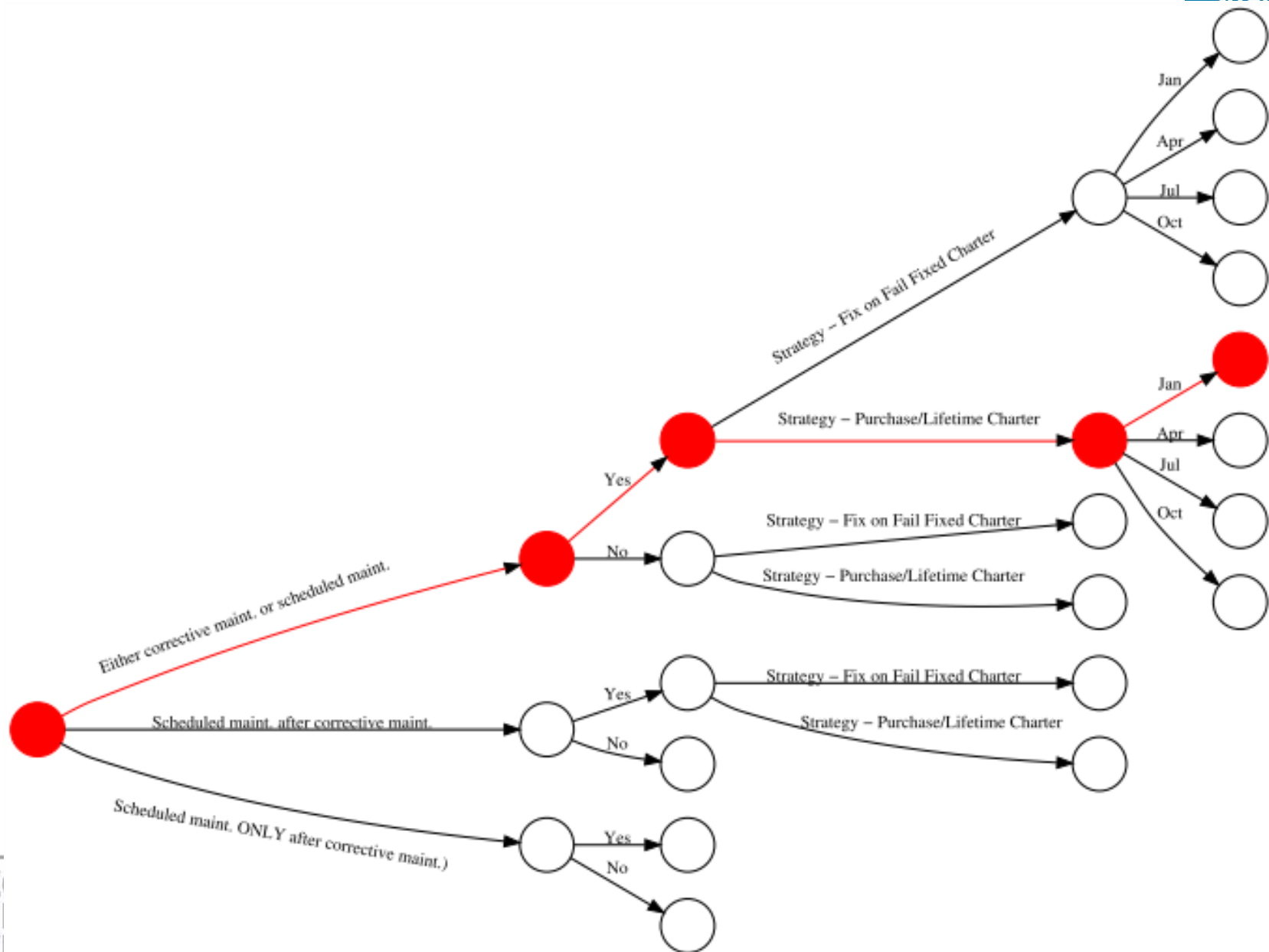


Emulator for StrathOW-OM

- The emulator “learns” from a given set of simulation results.
- Essentially it is a mixture of interpolation, multivariate approximation (using neural network), and decision tree.
- Decision trees are needed because of non-numerical (ordinal) variables.
- Neural Networks learn the mapping of numerical (cardinal) variables.



Ordinal Variables in the Emulator



Web Interface to Emulator

Emulator Query

127.0.0.1/cgi-bin/rcgi.tcl/formgen.R

Emulator Query

Output Variable

Lost Power (kWhr)

Input Variables

CTV Tech. Maintenance Schedule	Helicopter Usage	Jack-up Charter	Scheduled maintenance Start Month	Shift Start	Helicopter Flying Hour	FSV Charter	Jack-up charter
Either corrective maint. or scheduled maint.	Yes	Strategy - Fix on Fail Fixed Charter	Apr	6.5	550	10	25
Scheduled maint. after corrective maint.	Yes	Strategy - Purchase/Lifetime Charter	Jul	7.5	650	15	30
Scheduled maint. ONLY after corrective maint.	No	Strategy - Purchase/Lifetime Charter	Jul	8.5	0	21	35
Scheduled maint. after corrective maint.	Yes	Strategy - Fix on Fail	Jan	9.25	675	27	44

Add Row

Submit

Choose

Strategy - Fix on Fail Fixed Charter

Strategy - Purchase/Lifetime Charter

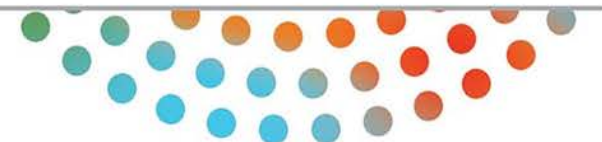
Emulator Result

127.0.0.1/emulator_responses/fd79aac3-409b-3e42-bb13-4fb113559c2b.html

CTV.Tech..Maintenance.Schedule	Helicopter.Usage	Jack.up.Charter	Scheduled.maintenance.Start.Month	Shift.Start	Helicopter.Flying.Hour	FSV.Charter	Jack.up.charter	Lost.Power..kWhr.
Either corrective maint. or scheduled maint.	Yes	Strategy - Fix on Fail Fixed Charter	Apr	6.5	550	10	25	887358447.311383
Scheduled maint. after corrective maint.	Yes	Strategy - Purchase/Lifetime Charter	Jul	7.5	650	15	30	607280992.721832
Scheduled maint. ONLY after corrective maint.	No	Strategy - Purchase/Lifetime Charter	Jul	8.5	0	21	35	104373299.516843
Scheduled maint. after corrective maint.	Yes	Strategy - Fix on Fail Fixed Charter	Jan	9.25	675	27	44	734733331.492885

Conclusion

- Mothership concepts can bring a considerable advantage when the distance between offshore wind farm and port is long (>50 nautical miles).
- Fixed platforms can be considered in shallow waters; however, for deeper waters, mothership concepts are expected to be considered in offshore wind O&M fleets.
- Mothership concepts increase winter availability more than summer availability. If a mothership is not chartered for winter, productive period is expected to be significantly short.
- The most favourable alternative is significantly dependent on the climate, distance, water depth, failure rates, CTV fleet size, turbine capacity and wind farm size. Therefore each case should be investigated individually.





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