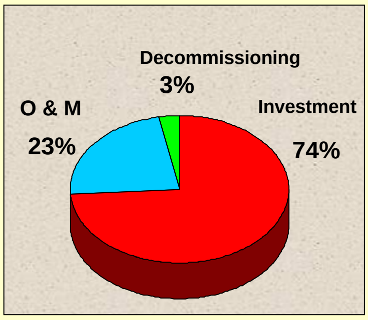
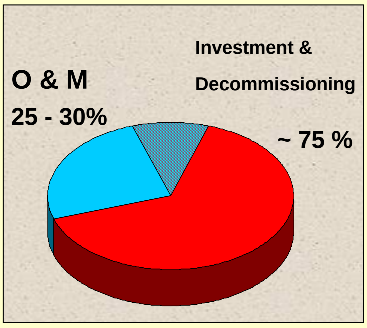
Typical contribution to energy cost

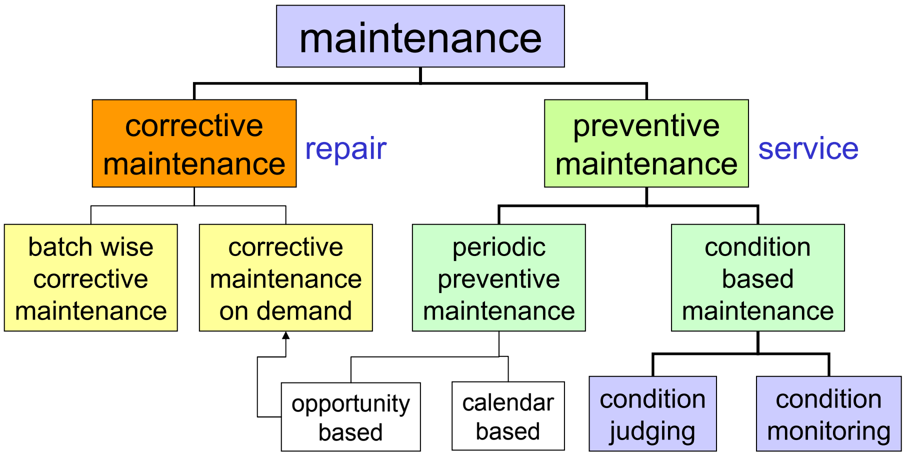


Opti-OWECS study (1998)



CA-OWEE (2001)

Maintenance Concepts



Failure frequencies 500kW class

	Tacke TW600	Enercon 40	Vestas V39/500
number of turbines	25	26	59
	events/year	events/year	events/year
Lightning	0	0.03	0
Blade	0.76	0.42	0.32
Rotor Brake	0	0	0
Pitch Mechanism	0	0.30	0.03
Brake	0.08	0	0
Shaft/Bearing	0.04	0.03	0
Gearbox	0.16	0	0.03
Generator	0	0.03	0.33
Hydraulic	0.32	0	0.27
Yaw System	0.32	0.23	0.08
Anemometry	0	0	0.01
Electronics	0.04	0.42	0.33
Electric	0.20	0.69	0.30
Inverter	0	0	0
Sensors	0.08	0.07	0.18
Other	0.20	0.38	0.37
Overall Total	**2.2**	**2.6**	**2.25**

Failure frequencies **2.2** **2.6** **2.25**

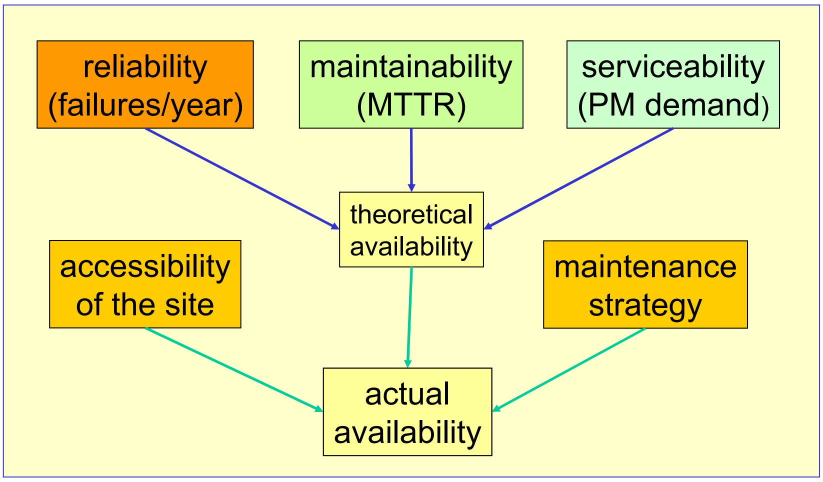
For larger machines (onshore) => **2.2 /year**

Failure frequencies multi MWW class

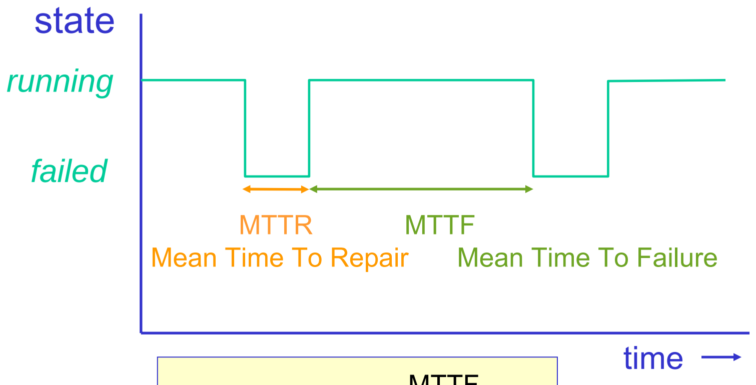
Component	Failure frequency (failures/year)
Shaft & Bearings	0.02
Brake	0.05
Generator	0.05
Parking Brake	0.05
Electric	0.14
Blade	0.16
Yaw System	0.23
Blade tips	0.28
Pitch Mechanism	0.28
Gearbox	0.30
Inverter	0.32
Control	0.34
Total	**2.20**

Total of all components: **2.20 failures/year**

Reliability, Availability, Maintainability, Serviceability

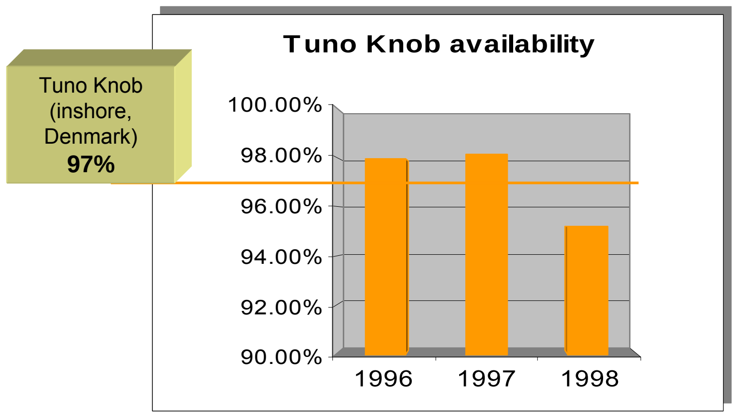


A measure for availability



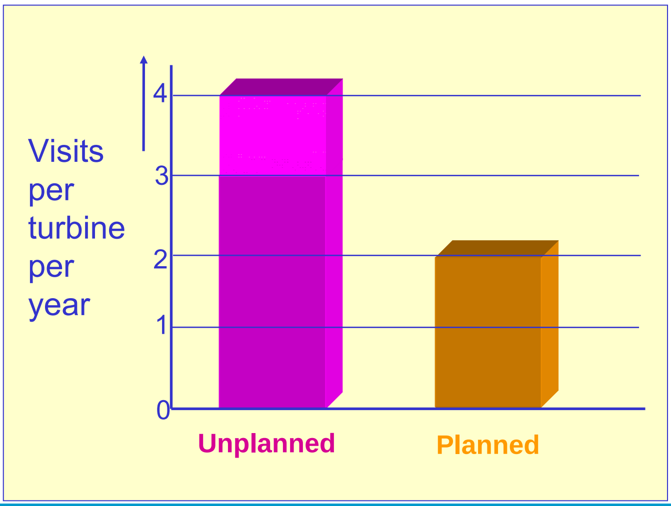
$$\text{Availability} = \frac{\text{MTTF}}{\text{MTTR + MTTF}}$$

Experienced Availability



Module 11: Operation & Maintenance

Present maintenance demand



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Module 11: Operation & Maintenance

Accessibility of site (Vessel)

Vindeby DK inshore

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Total
Nominal Working Days	23	21	20	22	20	22	19	19	21	23	210
Bad Weather (Days)	1	1	0	2	4	5	4	0	0	0	17
Bad Weather (o.5 Day)	5	2	2	4	1	3	1	0	0	0	18
Lack of Transport	0	2	0	0	1.5	4	6	1	0	0	14.5
Inaccessible Days	3.5	4	1	4	6	10.5	10.5	1	0	0	40.5
% Total Time	15.2	19	5	18.2	30	47.7	55.3	5.3	0	0	19.3

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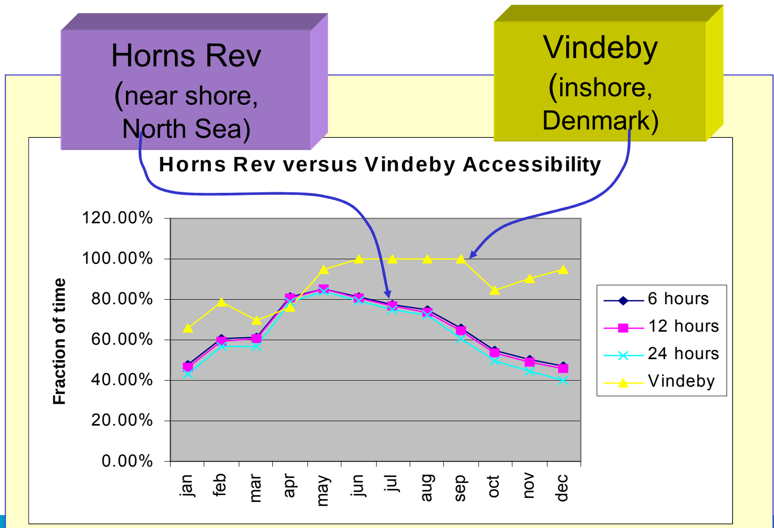
Module 11: Operation & Maintenance

Accessibility of site (Vessel)



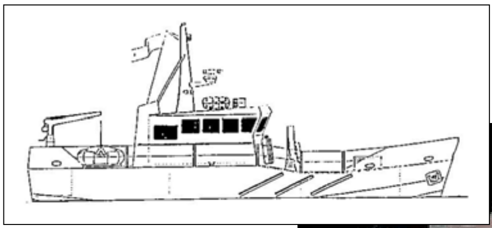
Module 11: Operation & Maintenance

Means of crew transport

- Helicopter
  - fast
  - expensive
  - helipad
  - large operational window

- Tender vessel
  - fairly slow
  - cheap
  - boat landing
  - medium window

Means of crew transport 2



A tender vessel
For crew transport

A "gol" boat
Harbour pilots

Means of crew transport 3

A tender vessel
For crew transport

With a Zodiac
for landing

Means of crew transport 4

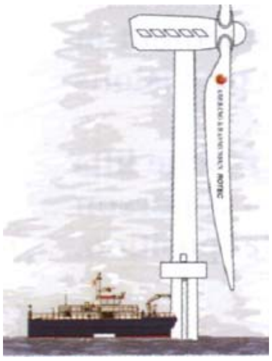
With a Zodiac
for landing ??

Means of crew transport 5

Crew transport
by helicopter

Trends: Access methods

Catamaran landing vessel



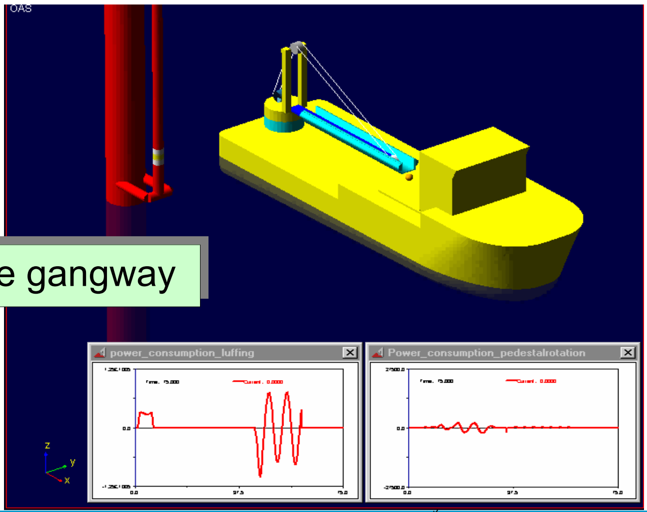
SWATH@A&R / Abeking &Rasmussen

Trends: Access methods

Flexible gangway:

OAS: P&R systems / Reinout Prins

Trends: Access methods

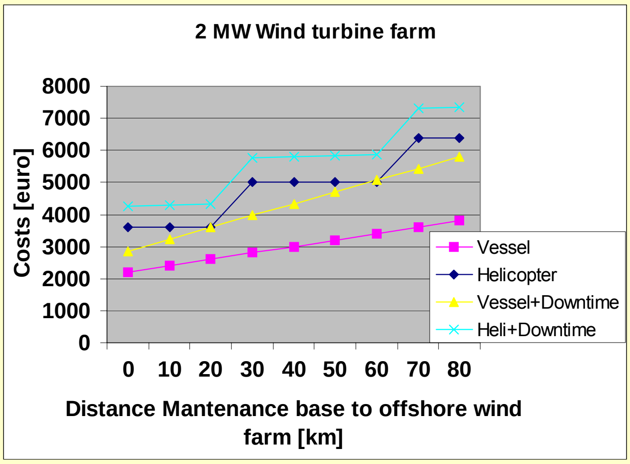


Flexible gangway

Trends: Access methods

Ampelmann

Cost comparison transport Vessel/Helicopter



Experiences in the real world

Maintaining Horns Rev:

- **Access by boat**: Winter 02/03: 5/7 days
  - » Winter 03/04: 1/7 days
- **Helicopter:** 6/7 days
- **Vestas responsible for crew** (60 people)
  Elsam for transport (6 people)
- **75.000 transfers in 1.5 years** (2 x /day/turbine)

Experiences in the real world

Maintaining Horns Rev:

Reasons:

– Design not well adapted for offshore
– Strategy not optimal
– Onshore crew
– Sophisticated alarms, but what does it mean?

Lifting equipment

- Jack-up barge
- Crane vessels
- Helicopter
- Jack up vessel

assisted with built-in facility (in wind turbine)

Installation & O&M lifting facilities

Jack up vessels

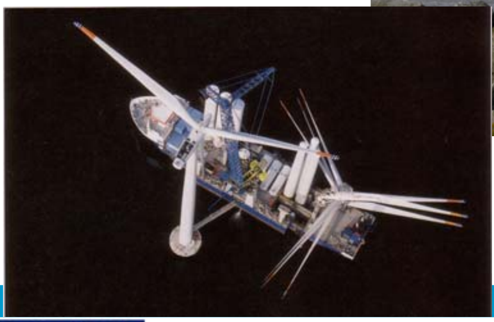
Utgrunden Wind farm, Sweden

A2Sea Ocean Hanne at Horns Rev Denmark

Module 11: Operation & Maintenance

Installation and O&M lifting facilities

Jack up vessels



A2Sea Ocean Hanne at Horns Rev and at Nysted Denmark

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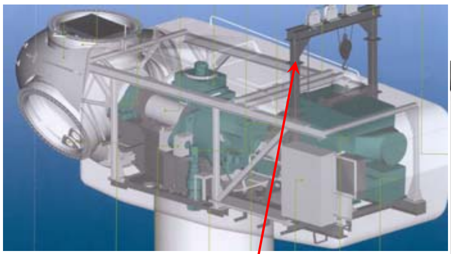
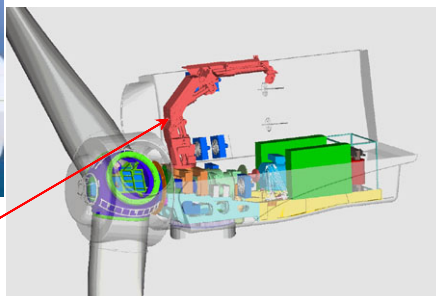
Trends: Lifting at wind turbine

Hoisting outside



Picture: Enron (Utgrunden, Sweden)



Picture: Nordex N80 Offshore

Internal cranes

Trends: Installation

Ballast-Nedam NEG-Micon Dowec project

Maintenance strategies

- PM and CM on demand
  (onshore practice)
- Opportunity based maintenance
  (PM when CM is demanded)
- Condition based maintenance
  (PM and CM only when demanded)
- No maintenance/ batch maintenance

Module 11: Operation & Maintenance

Maintenance strategies

- PM and CM on demand
  (reduced PM demand, increased reliability)
- Opportunity based maintenance
  (flexible PM interval, increased reliability)
- Condition based maintenance
  (extensive condition monitoring)
- No maintenance/ batch maintenance
  (only feasible when failure freq. < 0.2 /year)

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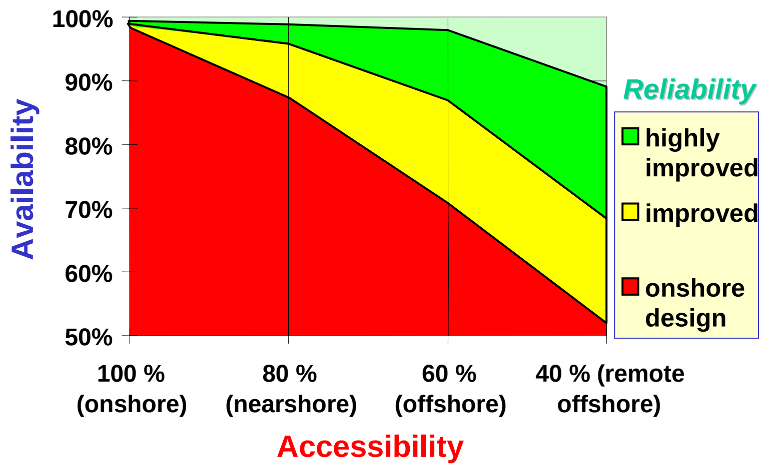
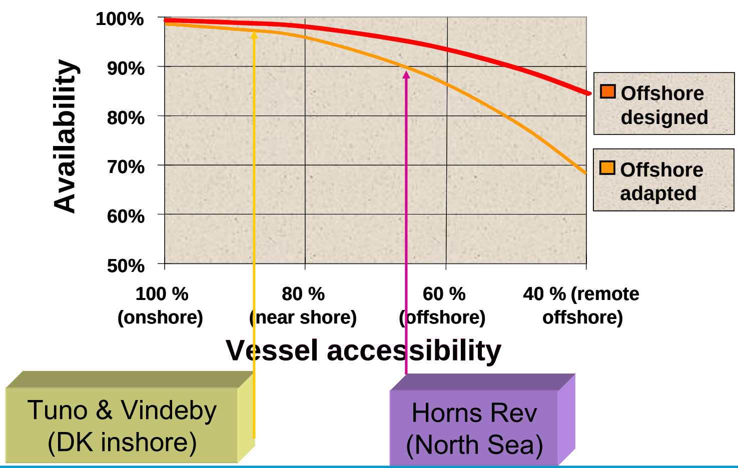
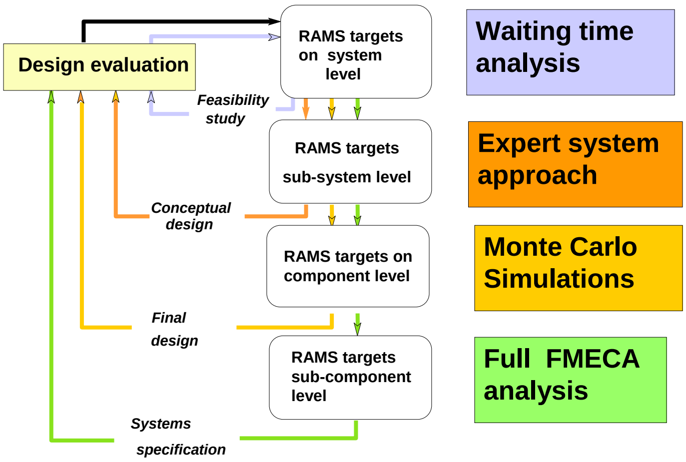
Importance of *Reliability* and *Accessibility*



Importance of (improved) Reliability

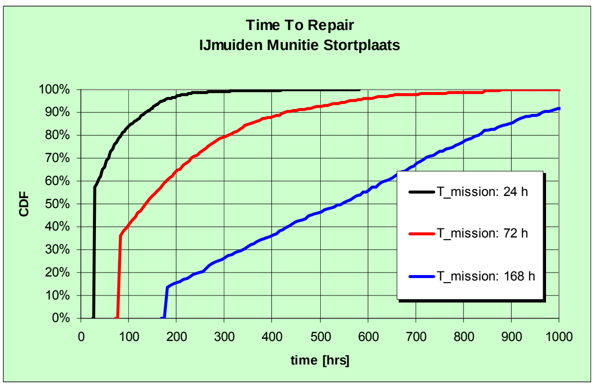


Assessing reliability, availability and O&M in the design process



Probabilistic Waiting time analysis

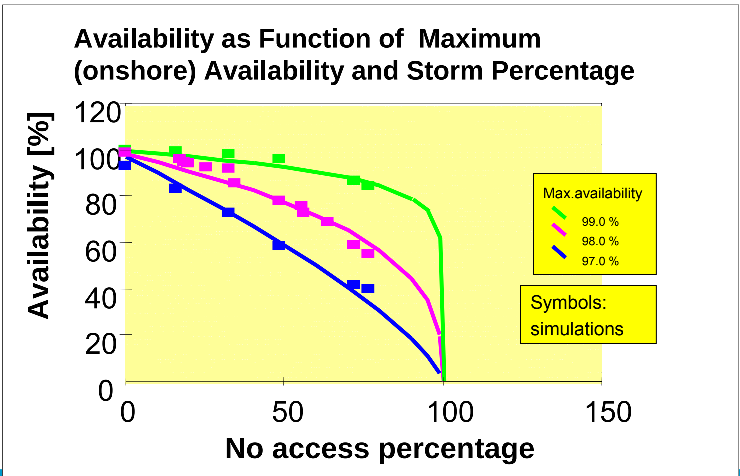
Chance [%]



ECN/ Luc Rademakers

Time [hrs]

Trend lines in expert system



Monte Carlo simulations

- Analysis of complex stochastic processes
- Failure simulation of wind turbines
- Storm simulation for OWECS accessibility
- Availability estimates for OWECS
- O&M costs estimates for OWECS

FMECA: Failure Mode Effect and Criticality Analysis

- systematic brake down of:
  - functional components
  - hardware component
- analysis of:
  - effects of all kinds of failures upon functioning
  - criticality of failure (how does failure affect costs/environment)

Reliability vs. turbine design

- Turbine design gets more complex:
  - Three bladed, variable speed pitch control
  - Doubly fed generators, Inverters

BUT

- Offshore environment demands a robust, lean design:
  - Two blades !?
  - Stall control !??
  - Low speed or Direct drive generator !?

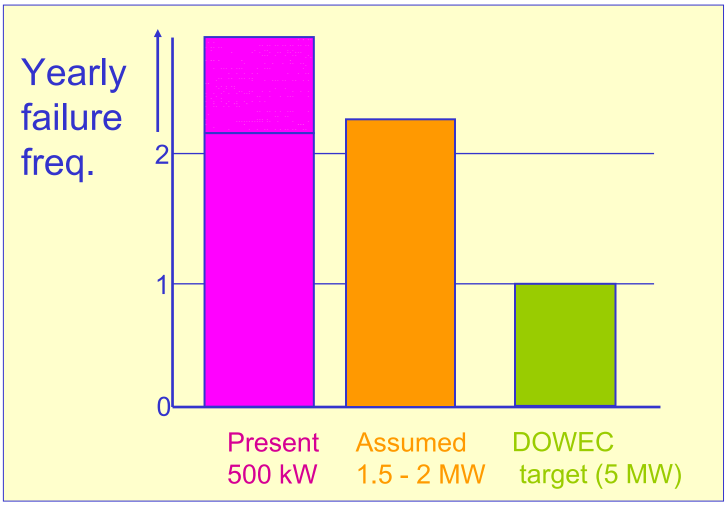
Recent wind turbine failures

Context of the DOWEC project

- Consortium of industries and institutes
- Project: ~ 500 MW offshore wind farm
- Location: North Sea > 12 mile zone
- Concepts of 5 MW wind turbines
- Turbine design for large scale wind farm

Assess wind turbine RAMS aspects in the context of the whole wind farm

Wind turbine's reliability



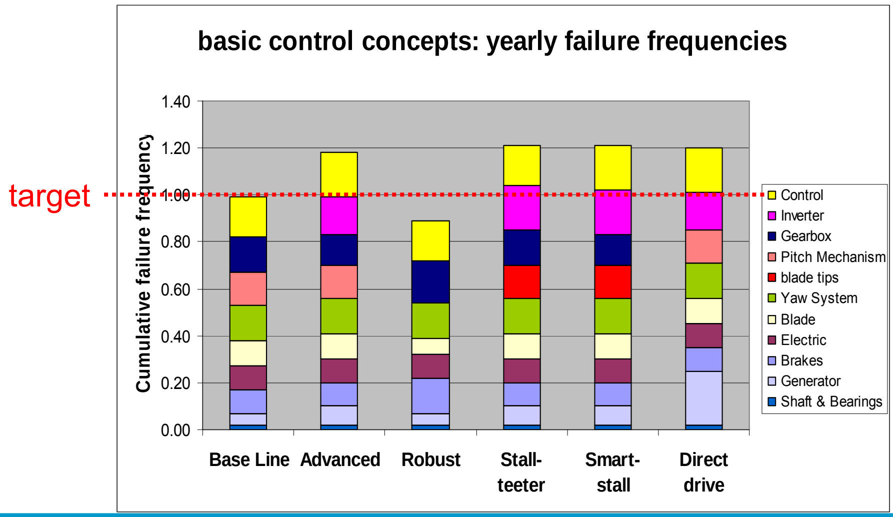
Reduction of failure frequencies

Components	factor	events/year
• Electric system	0.7	0.10
• Blades	0.7	0.07 / 0.11
• Yaw System	0.65	0.15
• blade tips	0.5	0.14
• Pitch Mechanism	0.5	0.13 / 0.14
• Gearbox	0.5	0.13 / 0.15
• Inverter	0.5	0.16
• Control system	0.5	0.15 / 0.19

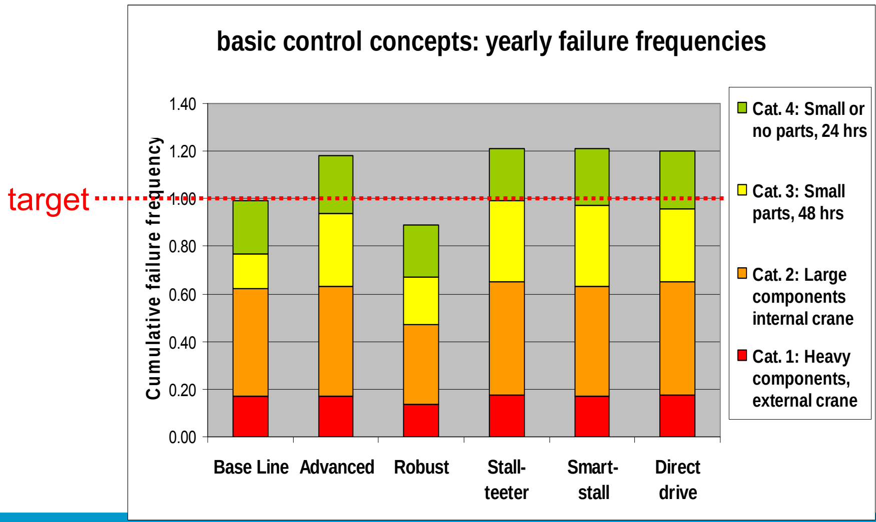
DOWEC concepts

Base line	Advanced	Robust	Stall-teeter	Smart stall	Direct drive
Active Stall	Pitch	Stall	Stall	Stall	pitch
3 blades	3 blades	2 blades	2 blades	3 blades	3 blades
2 speed	Var. speed (30%)	Fixed speed	Var. speed (full)	Var. speed (full)	Var. speed (full)
Tubular tower	Tubular tower	Tubular tower	Truss tower	Tubular tower	Tubular tower
Piled (tripod)	Piled (tripod)	Monopile	Gravity	Piled (tripod)	Piled (tripod)
Up wind	Up wind	Up wind	Down wind (teetered hub)	Up wind	Up wind

DOWEC concepts: reliability

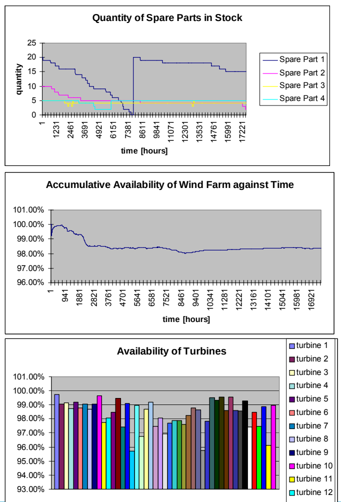


DOWEC concepts: failure classes

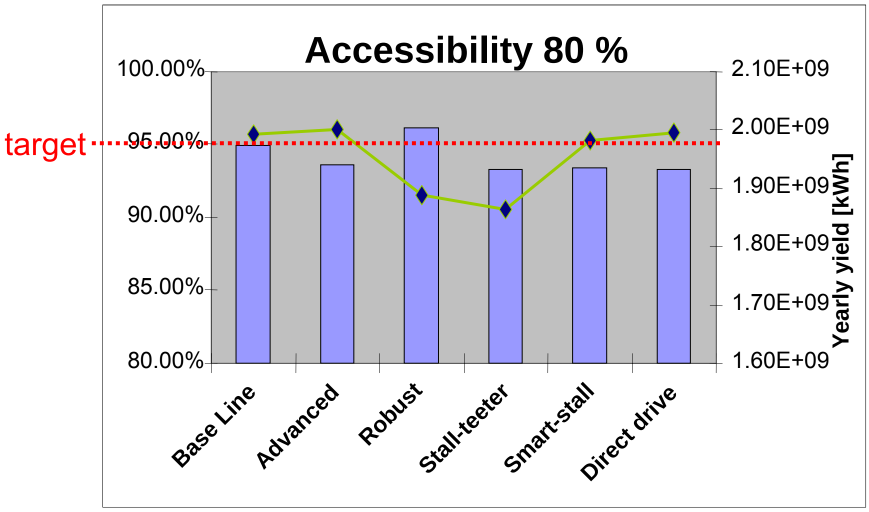


Numerical Monte Carlo Simulation

- Site conditions (wind and waves)
- Failures
  components of turbine, and wind farm
- Maintenance strategy
  - ships and crew
  - immediate/batch repair
  - overhaul
  - stock keeping

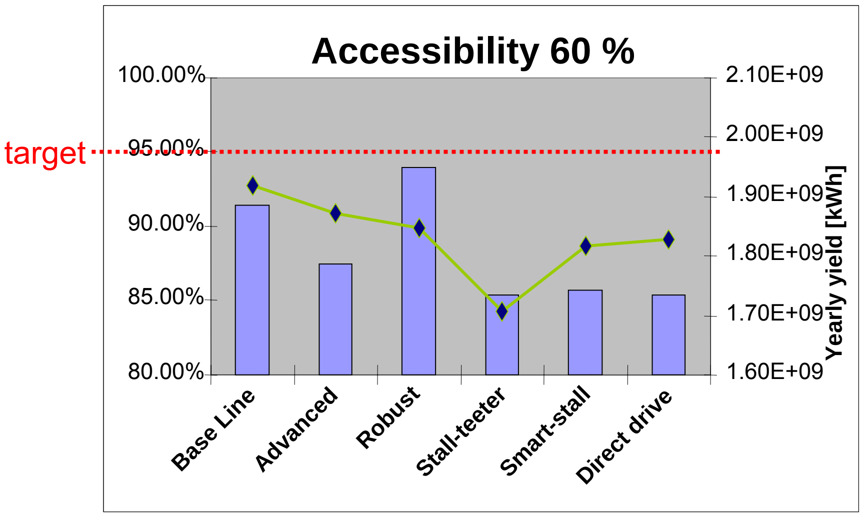


DOWEC 500 MW wind farm

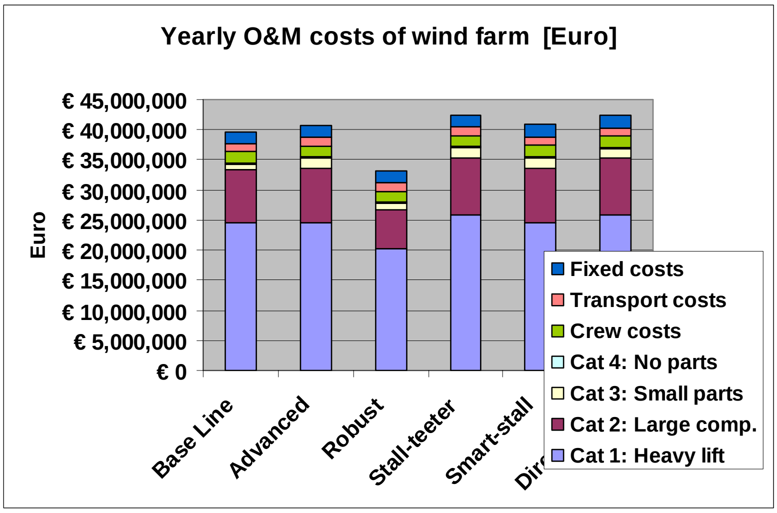


Module 11: Operation & Maintenance

DOWEC 500 MW wind farm



DOWEC 500 MW wind farm



Context of the DOWEC project

- Consortium of industries and institutes
- Project: ~ 500 MW offshore wind farm
- Location: North Sea > 12 mile zone
- Concepts of 5 MW wind turbines
- Turbine design for large scale wind farm

⇨ Develop optimal crew transport strategy

The Target

Develop an optimal O&M strategy for crew transport in the DOWEC offshore wind farm

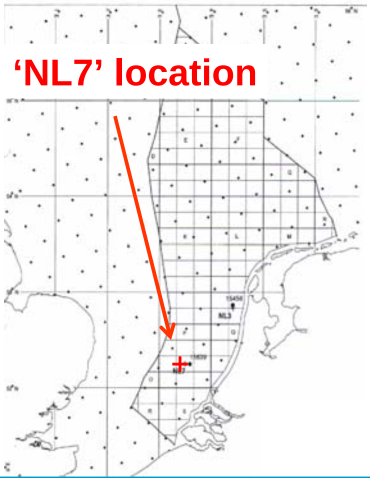
- 80 * 6 MW wind turbines
- 43 km off the Dutch coast ("NL7")
- 40 PM operations per year
- 1.5 failure per year per turbine
  (120 (averaged) CM operations per year)
- 1 shift (12h) per 24 hours

Access systems considered

No	Access system	Significant wave height [m]	Average (1-hour) wind speed [m/s]
1	Fictitious	0.75	N.A.
2	Rubber boat, jump onto ladder	1.5	10
3	Offshore Access System (OAS)	2	11.5
4	Offshore Access System + (optimistic assumption)	3	15
5	Helicopter	NA	20

Wind & waves from the NESS/NEXT database

- North European Storm Study
- consortium of oil companies
  (“NL7“ data made available by Shell)
- “hindcast“ data
  - wind fields based on pressure data
  - application of wave models
  - verification with measurements
- 3- hours interval; 30*30 km grid
- 30 years;   9 years complete
  (long term correlation of wind and waves)



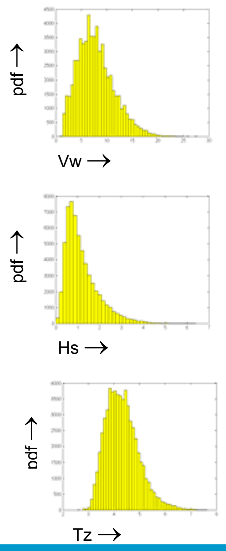
Variables in the NESS/NEXT database

Characteristic values for each 3-hour period:

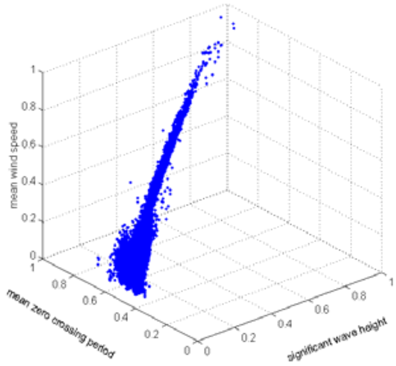
- $\underline{V}$ (1-hour) mean wind speed (m/s) at 10 m height
- θ_V wind direction (degrees)
- H_s significant wave height (m)
- T_z mean zero upcrossing period (s)
- Θ_m wave direction (degrees)

9 years of consecutive data

From 3 D scatter plot



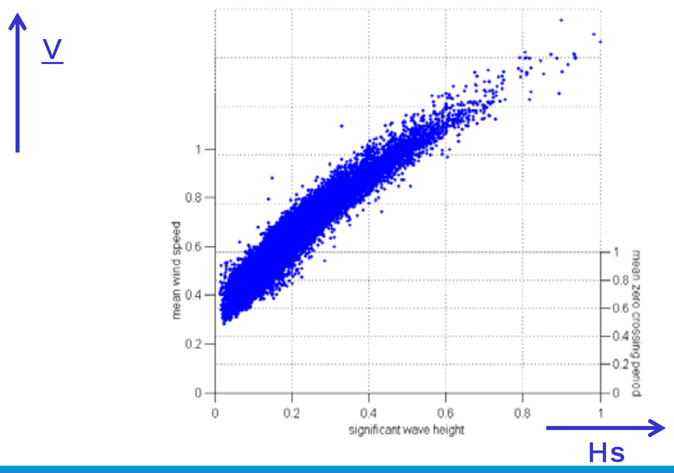
- ?
- ⇒



NEXT database: built-in (long term) correlation between wind and wave data

Module 11: Operation & Maintenance

To 2 D relations



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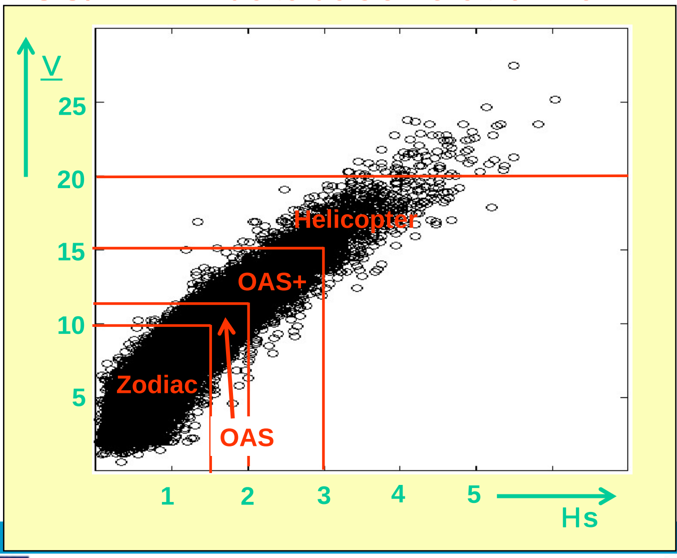
NESS/NEXT database relation for NL7



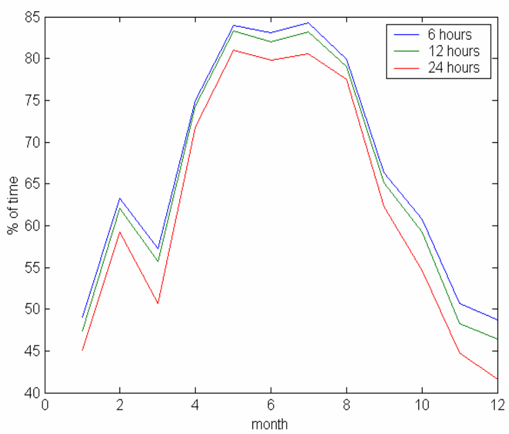
Weather windows 1

Example:

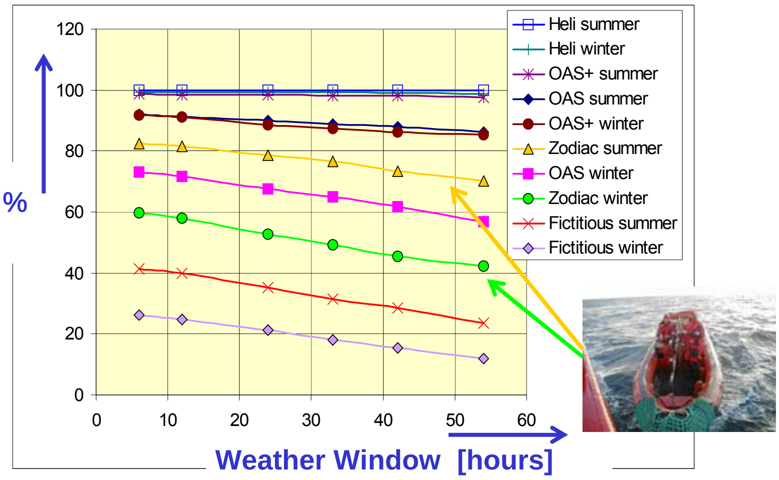
- Uninterrupted time intervals H_s < 1.25 m

Windows:

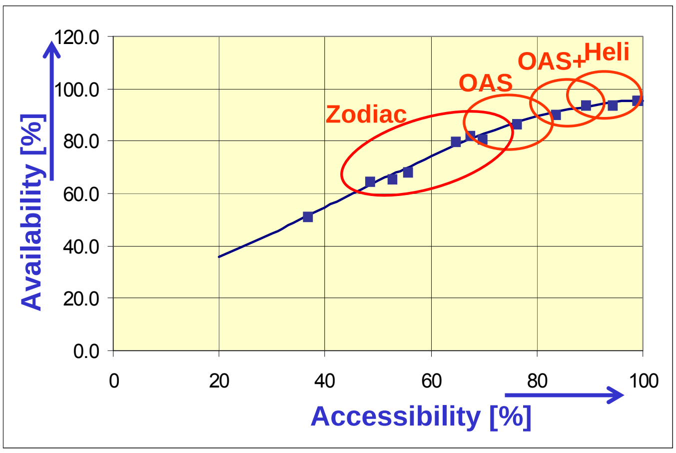
- 6 hours
- 12 hours
- 24 hours
- ...... hours



Weather windows 2

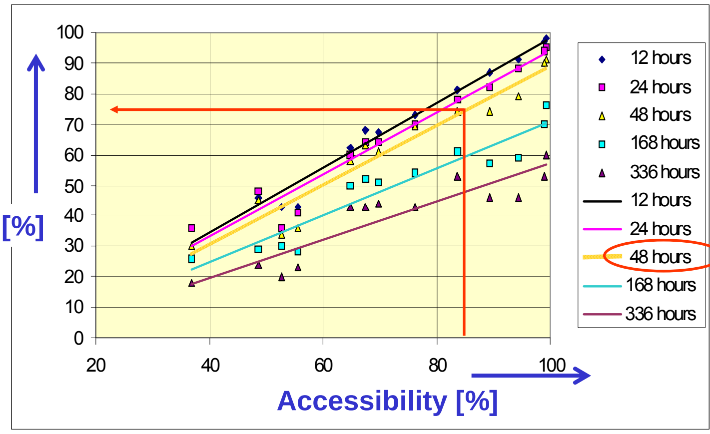


Availability of the DOWEC wind farm



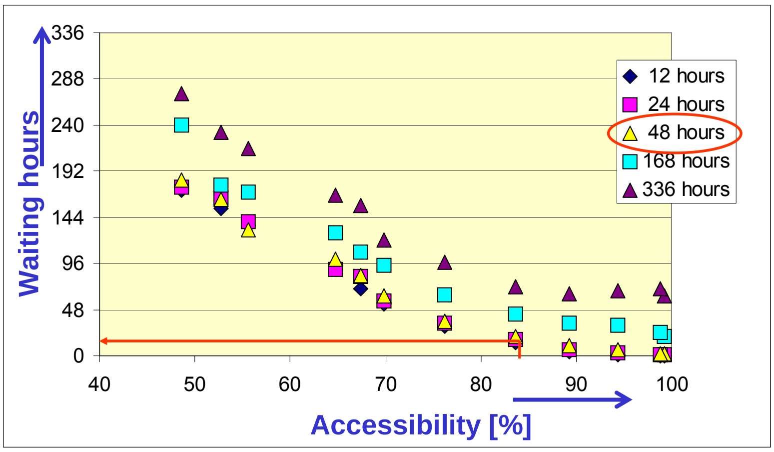
Module 11: Operation & Maintenance

Immediate maintenance action



Module 11: Operation & Maintenance

Average waiting time



CONTOFAX overall results

DOWEC reference wind farm: one shift with two crews

No	Access system	Accessibility [%]	Availability [%]
1	Fictitious	34	49
2	Rubber boat, jump onto ladder	71	83
3	Offshore Access System	84	91
4	Offshore Access System**+** (optimistic assumption)	95	95
5	Helicopter	100	96

DOWEC crew transport conclusions

- Rubber boat landing strategy not feasible
- OAS wind farm availability > 90%
- OAS+ availability > 95%
- OAS+ and heli comparable availability
- Average waiting time for short maintenance actions (<48h) is limited (10 to 20 h)

O&M Conclusions

- **Present wind turbine reliability insufficient**
  - Certainly for wind farms at remote sites
- **Different maintenance strategy needed**
  - Opportunity based (flexible service intervals)
  - Condition based maintenance
- **High impact of heavy lifting operations on costs**
- **Large offshore wind farms need integrated design**
  - Wind turbines designed for marine maintenance (and installation !!) operations
  - Special purpose O&M hardware