Results of a comparative risk assessment of different substructures for floating offshore wind turbines

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Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m

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Introduction: Project background

- Overview
  - Horizon 2020 project, 12 partners, 7+ M€
  - 40 months, started 06/2015
- Objectives
  - Development of a methodology for evaluation and qualification of floating wind substructures
  - Progressing two designs to TRL 5 for 10MW wind turbines

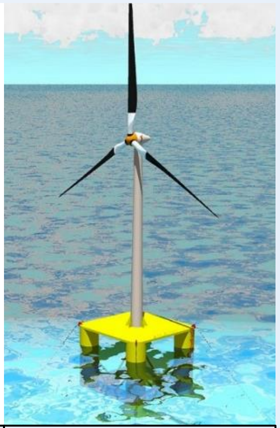
Introduction: Project background

- 4 substructures for floating wind turbines
  - TLPWIND (steel TLP)
  - IDEOL (concrete barge)
  - NAUTILUS (steel semi-sub)
  - OO-STAR (concrete semi-sub)
- More info at
  - http://lifes50plus.eu/

TLPWIND

IDEOL

OO-STAR



NAUTILUS

LIFES50+

Introduction: Task at hand

- Technology risk assessment
  - of 4 very different systems
  - of 3 locations with different legislations and environment
  - as a comparative study
  - across 4 consequence categories
    - cost, availability, H&S, environment
  - part of a wider substructure evaluation
    - financial (LCoE), technical (KPIs) and life cycle assessments (GWP, AdP and PE)

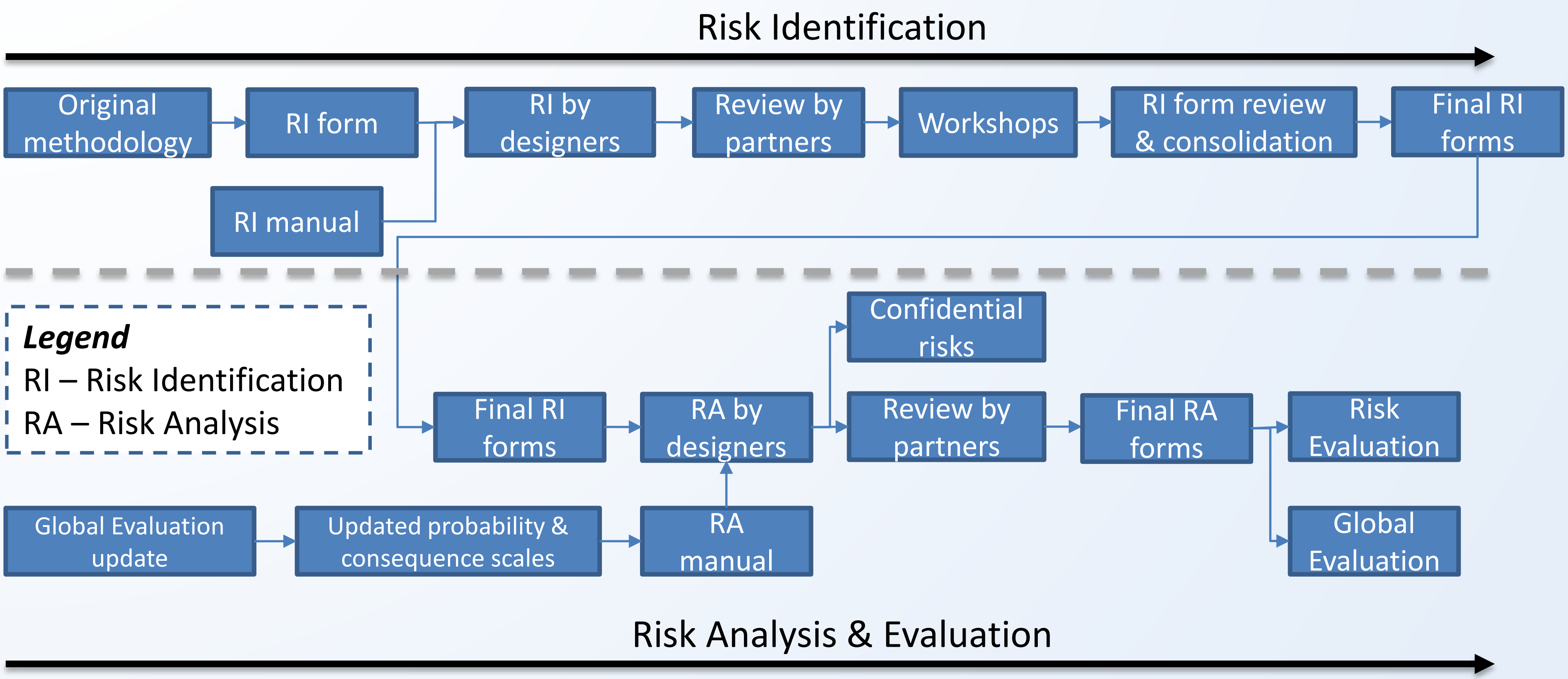
Methodology: Background

- Based on methodology developed in LIFES50+
- Based on standard techniques

- Uses functional decomposition (as opposed to structural), novelty categorisation
- A highly iterative process

Methodology: Background

- ‘Medium-level’ flow diagram



Methodology: Challenges & solutions

- Differentiation between designs
  - Conditional probability (aka β-factor)
    - Modified risk calculation formula
- Level playing field
  - Predefined failure effect, HAZID form consolidation, manual development
- Data confidentiality
  - 1-2-1 workshops, data anonymisation
- Risk part of a wider evaluation
  - MCDM with weighting factors, modified probability and consequence scales

Methodology: Challenges & solutions

- A hypothetical example

Design	Hazard	Potential Failure Cause	Failure Effect	Current Control	Probability	Conditional Probability (β-factor)	Consequence			
							Cost	Availability	H&S	Environment
A	Mooring line failure	Underestimated fatigue loading	Loss of stability resulting in loss of structure	• Design to standard • Wave tank tests • Numerical simulations • Independent 3rd party review	1	Possible	5	5	1	5
B				• All from the above (A) + • Redundancy	1	Highly unlikely	5	5	1	5

(Assumes direct link between *Potential Failure Cause* and *Hazard)*

LIFES50+

Results: Risk identification

- ~80 risks identified after risk identification response consolidation
- Functions used in risk identification
  - Buoyancy, stability, station keeping, structural integrity, power transmission, RNA interfacing, monitoring and communications
- Good spread of risks across all functions
  - Fewest for buoyancy, and monitoring and communications
  - Most for station keeping
- Majority of risks seen as being of a low novelty categorisation
  - Proportionally, station keeping and power transmission are seen as having higher novelty associated with them

Results: Risk identification

- Life cycle phases used in risk identification
  - Design, manufacturing (construction and assembly), transportation and installation, O&M, decommissioning
- Risks spread across life cycle phases
  - Fewer risks for decommissioning
  - Most for design and O&M
- Importance on clear life cycle definition
  - Inception vs materialisation

Results: Risk analysis

- Very similar average risk scores across all functions and life cycle phases
- The highest average risk scores are
  - for functions that fall under direct remit of designers (e.g. structural integrity, buoyancy)
  - associated with severe failure effects
- The lowest average risk scores are
  - functions that are not under direct remit of designers
  - associated with loss of power production or inadequate working environment (shows high confidence in OEMs, installers and operators)

Results: Risk analysis

- Developed a generic list of risks for floating wind turbines (currently confidential)
  - Includes a list of various possible control measures

Function	Element	Hazard	Life Cycle Phase	Potential Failure Cause	Failure Effect	Control Measures
Buoyancy	Main buoyant body	Flooding of main buoyant body	O&M	Collision	Compromised buoyancy	• Compartamentalisation • Review and quality control • Periodic inspection • Signalling • Design for vessel impact resistance
Structural Integrity	Primary material	Insufficient structural capacity	Design	Design error (underestimation of extreme loading)	Collapse of the structure	• Detailed environmental studies • Design to standard • Independent 3rd party review and certification • Monitoring • Wave tank experiments
Stability	Passive ballasting	Unequal distribution of permanent ballast (solid or liquid)	Installation	Installation error	Compromised stability	• Compartamentalisation • Review and quality control • Experience from other industries

Results: Risk analysis

Source: Wind Power Offshore (Pic: Yumiuri Shimbun)

Results: Risk analysis

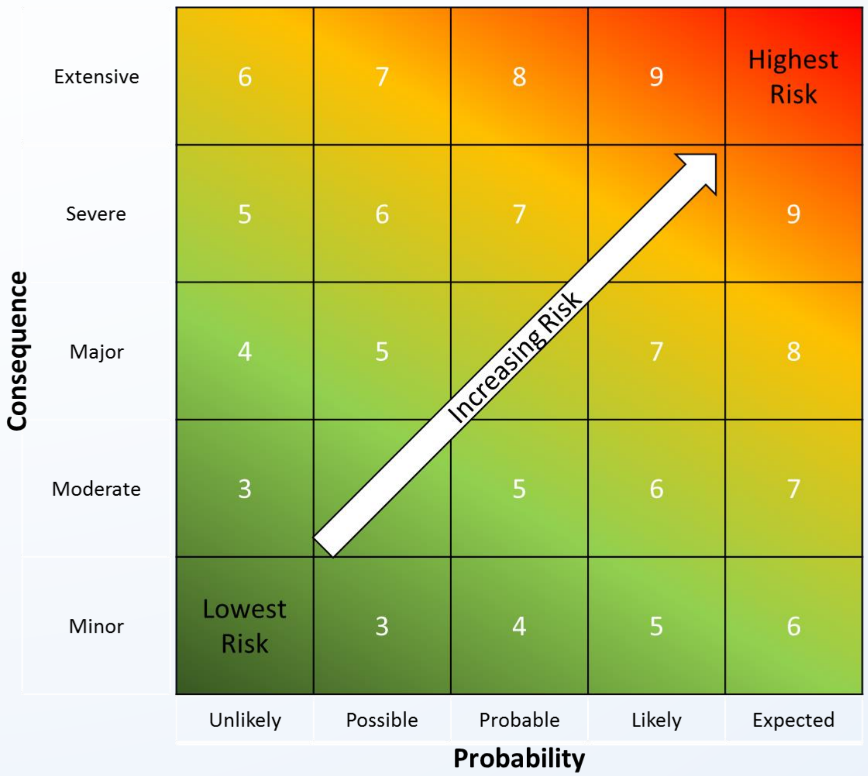
Function	Element	Hazard	Life Cycle Phase	Potential Failure Cause	Failure Effect	Control Measures
Station Keeping	Mooring lines	Mooring line(s) failure	Construction	Manufacturing error (e.g. exceedance of tolerances)	Compromised station keeping capabilities	• Review and quality control • Inspection • Component testing
RNA Interfacing	Full structure (transition piece + tower + RNA)	Excessive motions	Design	Underestimation of inclinations, accelerations and vibrations	Damage to RNA	• Design to standard • Use of proven numerical simulation tools • Wave tank experiments • Collaboration with OEMs • Independent 3rd party review and certification • Monitoring • Inspection
Power Transmission	Dynamic cable / umbilical	Damage to dynamic cable / umbilical	O&M	Unintended interaction / collision with foreign objects (e.g. vessels, debris)	Loss of power production	• Collaboration with OEMs • Layout redundancy • Experience from other industries
Monitoring and Communication	Structural monitoring	Partial or complete loss of structural hull stress monitoring information	O&M	Expected failure of sensors during operation	Collapse of the structure	• Sensor redundancy • Monitoring • Inspection

Results: Risk evaluation

- Risk evaluation helps in the decision of risk treatment (risk analysis vs risk criteria)
- Risk treatment not part of risk assessment (falls under risk management)
- Risk criteria is highly internal context dependent

Results: Risk evaluation

- A hypothetical example using average risk scores to show importance of well defined risk criteria



	Case 1		Case 2	
Category	Scale	No. of risks	Scale	No. of risks
Low	risk < 4	27	risk < 3.8	22
Medium	4 ≤ risk ≤ 7	50	3.8 ≤ risk ≤ 6	34
High	risk > 7	23	risk > 6	44

Future work

- H&S risk assessment for all life cycle phases
- O&M risk assessment
- Commercialisation risk assessment
- Revised technology risk assessment after optimisation of the substructures
- Combination of all of the above into a wider substructure evaluation
- Update of the original methodology

Thank You!

Questions?