Decision support for OWFs installation process including the risk of supply disruptions

EUROS Seminar – 4th Progress meeting

11 October 2017, Amsterdam RAI

Ashish Dewan and Georgios Leontaris

EUROS
Excellence in Uncertainty Reduction of Offshore wind Systems

TU Delft

Outline

- Introduction
- ECN offshore wind research
- ECN Install
- Purpose of study
- SEJ method for supply disruptions
- Preliminary results of case study

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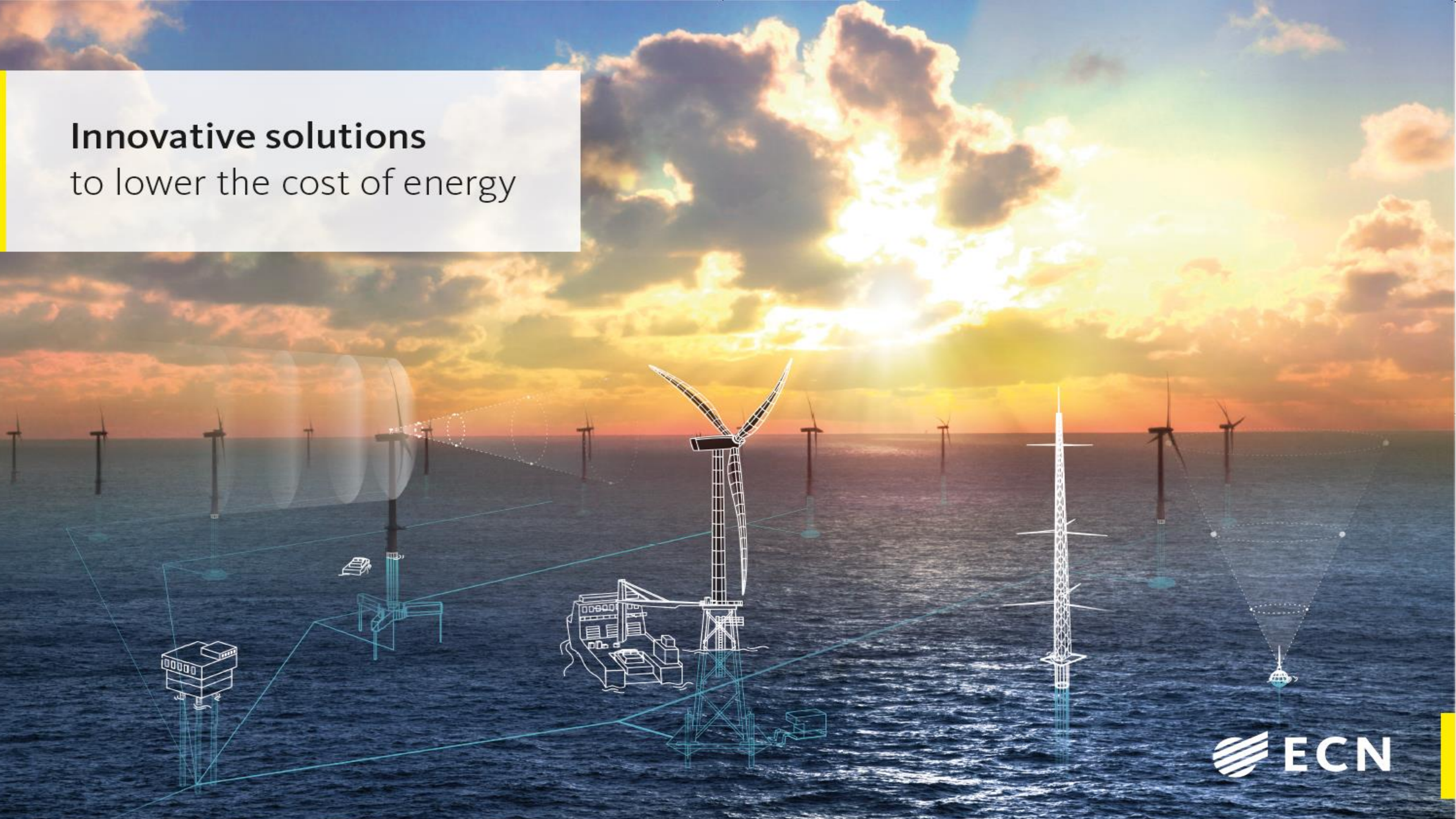
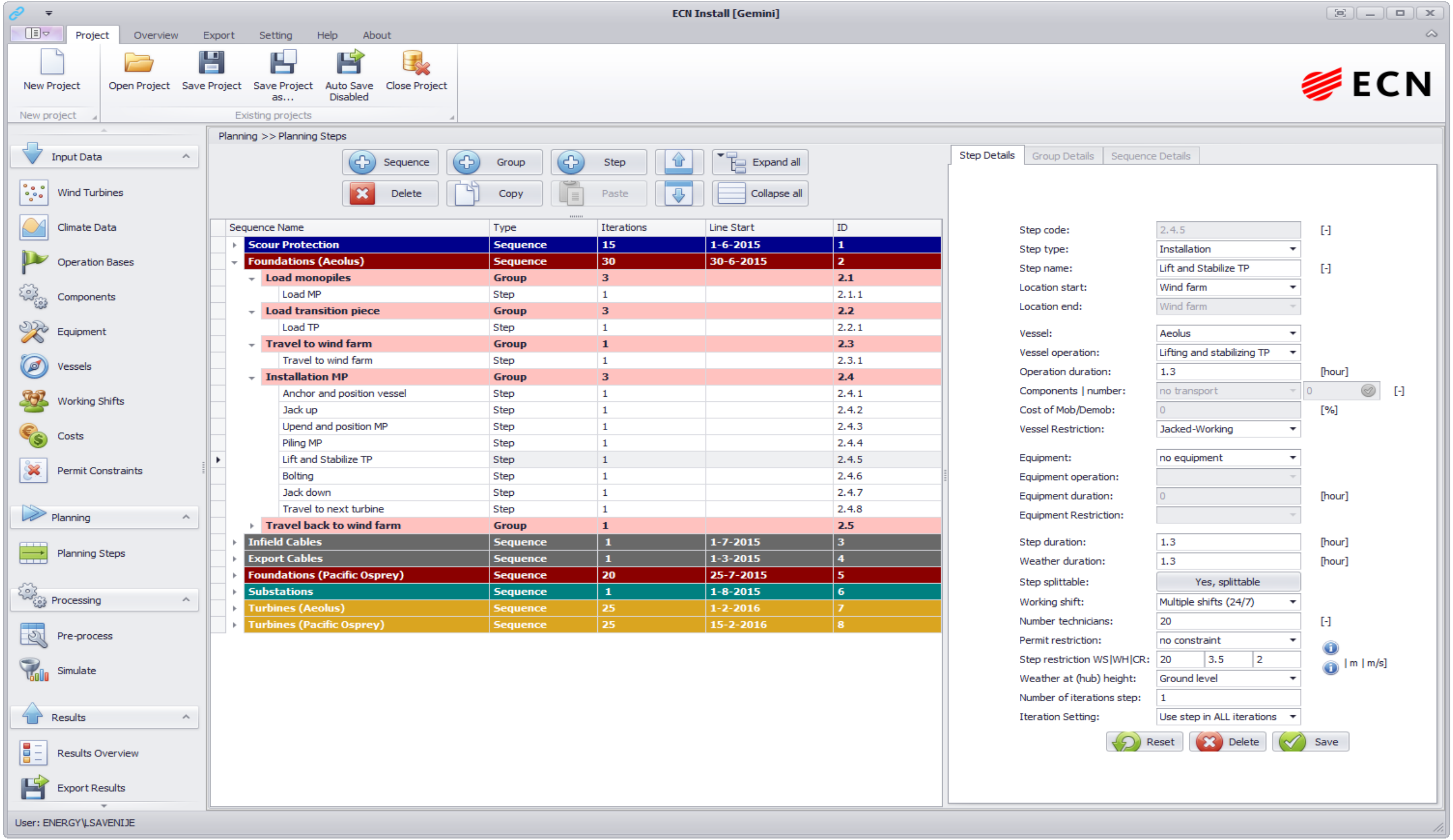
Innovative solutions
to lower the cost of energy



ECN Install

Modelling of the installation process


ECN Install [Gemini]
Project
Overview
Export
Setting
Help
About
New Project
Open Project
Save Project
Save Project as...
Auto Save Disabled
Close Project
New project
Existing projects
ECN
Input Data
Wind Turbines
Climate Data
Operation Bases
Components
Equipment
Vessels
Working Shifts
Costs
Permit Constraints
Planning
Planning Steps
Processing
Pre-process
Simulate
Results
Results Overview
Export Results
User: ENERGY\LSAVENIJE
Planning >> Planning Steps
Sequence
Group
Step
Expand all
Delete
Copy
Paste
Collapse all
Sequence Name | Type | Iterations | Line Start | ID
Scour Protection | Sequence | 15 | 1-6-2015 | 1
Foundations (Aeolus) | Sequence | 30 | 30-6-2015 | 2
Load monopiles | Group | 3 | | 2.1
Load MP | Step | 1 | | 2.1.1
Load transition piece | Group | 3 | | 2.2
Load TP | Step | 1 | | 2.2.1
Travel to wind farm | Group | 1 | | 2.3
Travel to wind farm | Step | 1 | | 2.3.1
Installation MP | Group | 3 | | 2.4
Anchor and position vessel | Step | 1 | | 2.4.1
Jack up | Step | 1 | | 2.4.2
Upend and position MP | Step | 1 | | 2.4.3
Piling MP | Step | 1 | | 2.4.4
Lift and Stabilize TP | Step | 1 | | 2.4.5
Bolting | Step | 1 | | 2.4.6
Jack down | Step | 1 | | 2.4.7
Travel to next turbine | Step | 1 | | 2.4.8
Travel back to wind farm | Group | 1 | | 2.5
Infield Cables | Sequence | 1 | 1-7-2015 | 3
Export Cables | Sequence | 1 | 1-3-2015 | 4
Foundations (Pacific Osprey) | Sequence | 20 | 25-7-2015 | 5
Substations | Sequence | 1 | 1-8-2015 | 6
Turbines (Aeolus) | Sequence | 25 | 1-2-2016 | 7
Turbines (Pacific Osprey) | Sequence | 25 | 15-2-2016 | 8
Step Details
Group Details
Sequence Details
Step code: 2.4.5 [-]
Step type: Installation
Step name: Lift and Stabilize TP [-]
Location start: Wind farm
Location end: Wind farm
Vessel: Aeolus
Vessel operation: Lifting and stabilizing TP
Operation duration: 1.3 [hour]
Components | number: no transport 0 [-]
Cost of Mob/Demob: 0 [%]
Vessel Restriction: Jacked-Working
Equipment: no equipment
Equipment operation:
Equipment duration: 0 [hour]
Equipment Restriction:
Step duration: 1.3 [hour]
Weather duration: 1.3 [hour]
Step splittable: Yes, splittable
Working shift: Multiple shifts (24/7)
Number technicians: 20 [-]
Permit restriction: no constraint
Step restriction WS|WH|CR: 20 3.5 2 | m | m/s]
Weather at (hub) height: Ground level
Number of iterations step: 1
Iteration Setting: Use step in ALL iterations
Reset
Delete
Save

Installation modelling

What can ECN Install do?

- Design and optimize the installation strategy for an offshore wind farm
- Determine project planning, delays, costs and risks

Source: Gemini

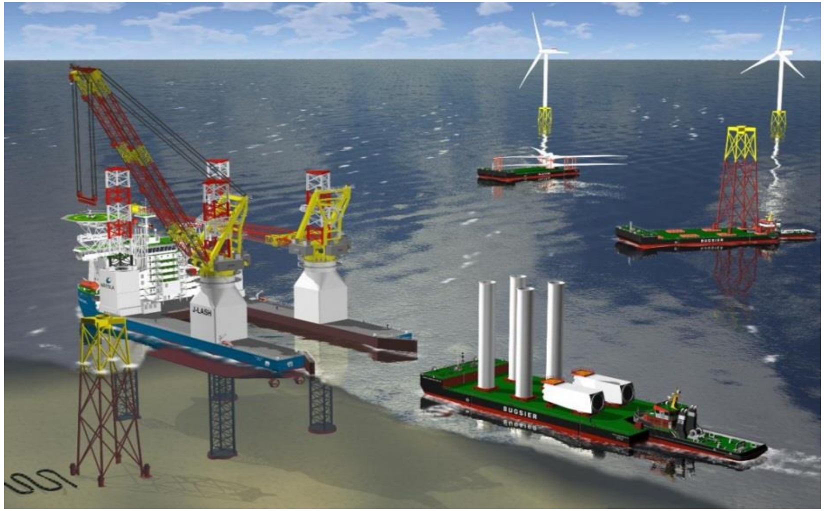
Source: Gemini

Installation modelling

What can ECN Install do?

- Commercial proof of new and innovative installation concepts
  - Installation methods
  - Support structures & wind turbines
  - Vessels and equipment

Source: Royal IHC



Source: Bugsier and Wärtsilä

ECN Install

Guiding platform

Master Student (TU Delft)

"Business Case evaluation for the right installation vessel"

HEEREMA

ECN Install Basic

ECN Experts

"Consultancy project for new innovative and commercial equipment providers"

YES!Delft

saitec engineering

ECN Experts

"Consultancy project for leading wind farm developers – assisting them with right installation strategy"

ECN

University of Tokyo

"Collaboration with other research organizations using ECN Install"

東京大学 THE UNIVERSITY OF TOKYO

ECN Install

Guiding platform for research on Installation

- Logistic Evaluation
- Onshore logistic & resources organiser

- Monitoring of the project- real time
- Update of the initial baseline
- Short-term decision making

- Risk Quantifier & Mitigator
- Risk impact on actual planning

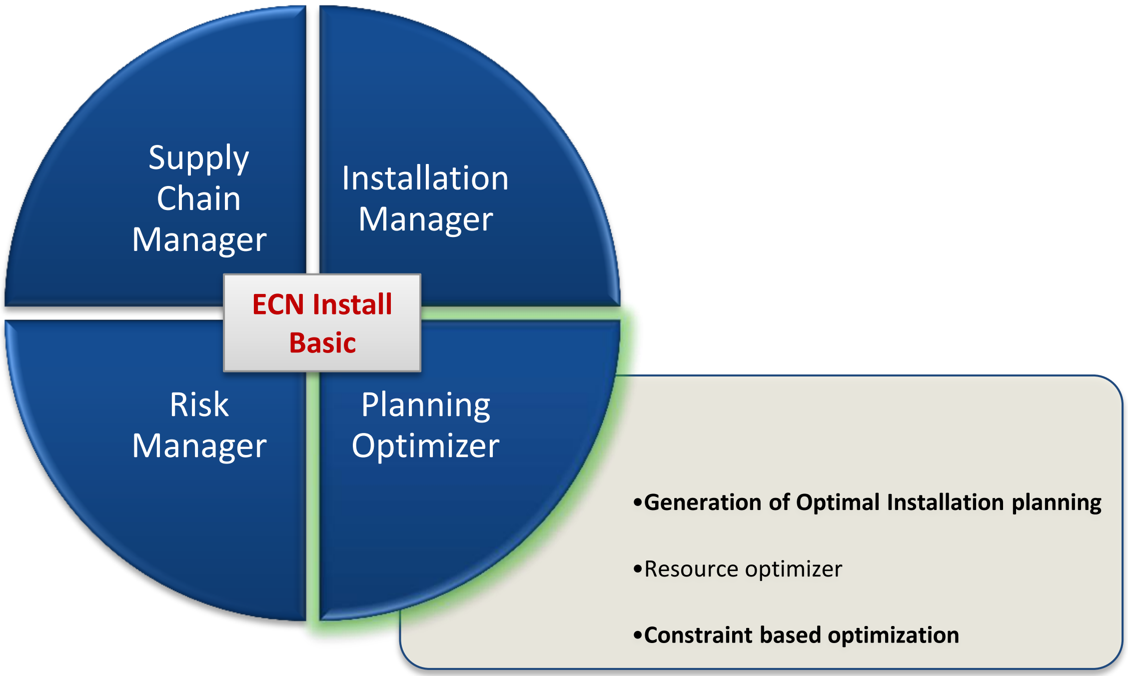
- Generation of Optimal Installation planning
- Resource optimizer
- Constraint based optimization

ECN Install

Guiding platform

Master Student (TU Delft)

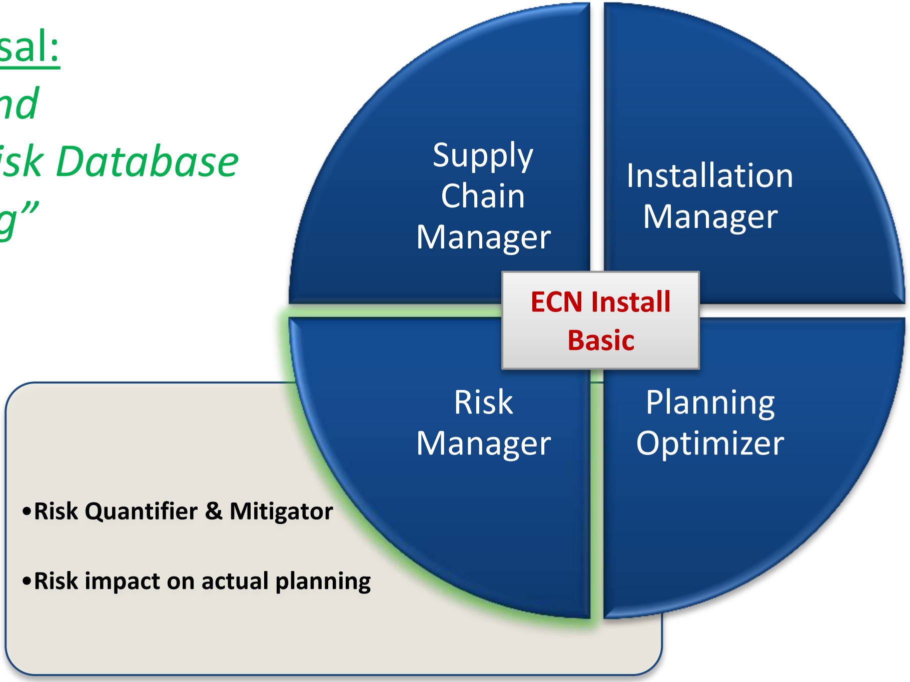
"Optimization of offshore wind farm installation procedure with a targeted finish date"



ECN Install

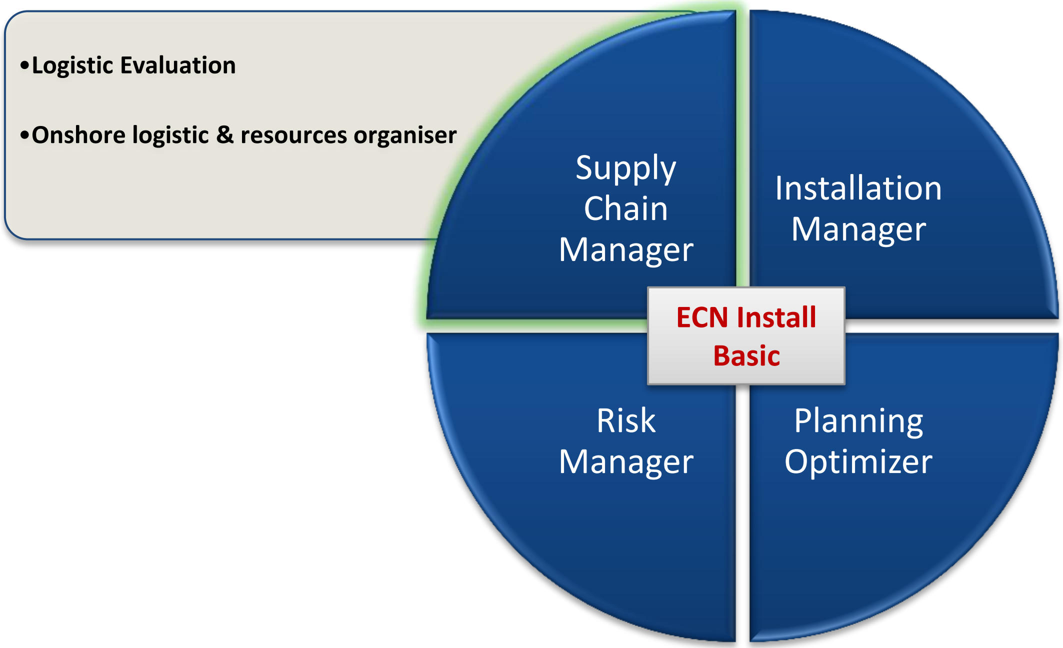
Guiding platform

GROW Proposal:
"Offshore Wind Installation Risk Database and Modelling"



ECN Install

Guiding platform



GBS JIP Project:

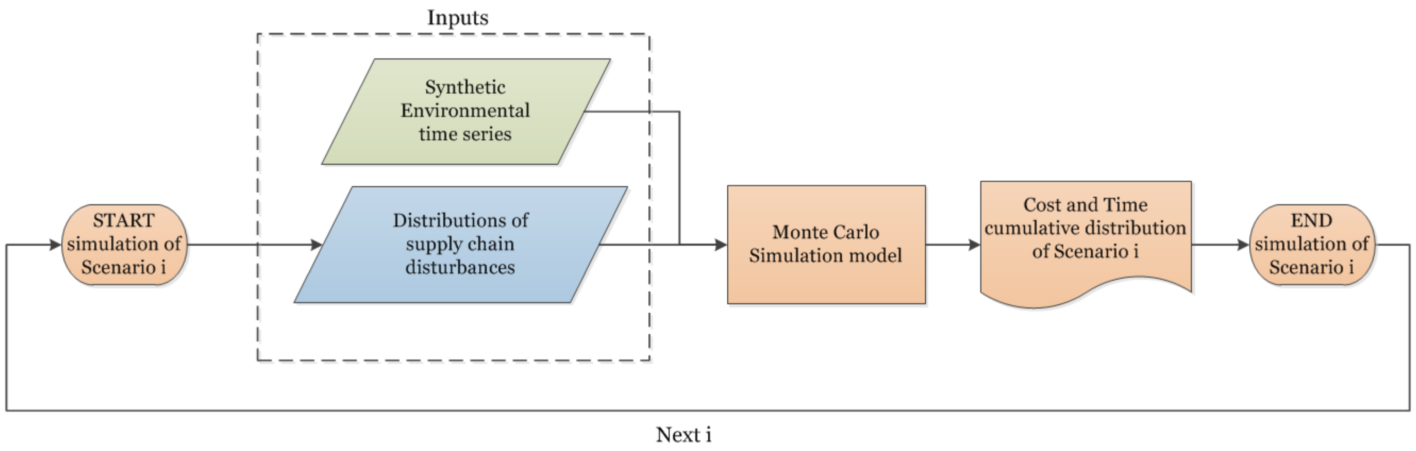
" Quantification of installation delays and cost for installing GBS – including the onshore construction and assembly"

EUROS Collaboration:

" Quantification of installation time and cost while considering the uncertainty of onshore logistics"

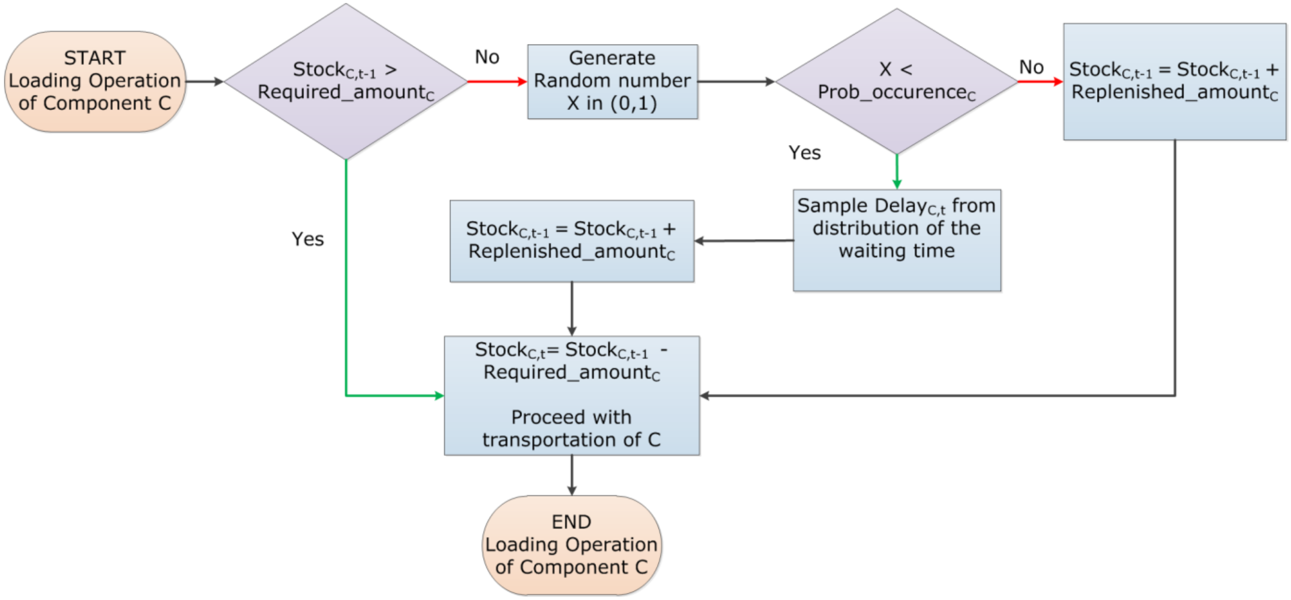
EUROS WP 3.1 Objective

- **Main goal**: probabilistic methods to support decision making and optimize the installation process of OWF while taking into account the predominant uncertainties



Algorithm to model supply disruptions

- Modelled as an event with a Probability of Occurrence and a Waiting Time distribution



Purpose of study

- Obtain distributions regarding the supply delays of different components during the installation process
- Projects with certain characteristics:
  - Location: North Sea
  - > 50 Wind Turbines
  - > 150 NM distance from manufacturer
- Serve as inputs for stochastic simulation model and assist in decision making concerning:
  - OWF installation schedule
  - Port selection
  - Installation Vessels' characteristics
  - Buffer stock
  - Insurance contracts

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Approach

- Lack of sufficient data regarding delays in the supply
- Expert opinions can be used to serve as inputs of simulation models
- Elicit expert opinions about uncertain events from a group of experts rather than a single expert
- Aggregate expert opinions based on each expert’s performance in assessing uncertainty
    - Cooke’s model for structured expert judgment (SEJ)

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SEJ description

- Questionnaire consists of:
  - Seed/Calibration questions (based on relevant data)
  - Questions concerning the variables of interest

- Experts are asked to provide individually the 5th, 50th and 95th percentile of their uncertainty distributions

- Performance in judging uncertainty measured in terms of:
  - **Statistical accuracy** $C(e_j)$
  - **Informativeness** $I(e_j)$ (the degree to which experts distributions are concentrated)

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SEJ – Combined opinion

- It is called Decision Maker (DM)
- Linear combination of weighted expert opinions
- Un-normalized weight: $w'(e_j) = 1_\alpha\left(\mathrm{C}(\mathrm{e}_\mathrm{j})\right) \times \mathrm{C}(\mathrm{e}_\mathrm{j}) \times \mathrm{I}(\mathrm{e}_\mathrm{j})$
- Normalized weight: $w(e_j) = w'(e_j) / \sum_{e=1}^{E} w'(e_j)$
- DM's density:

$$f_{DM,i} = \sum_{e_j=1}^{E} w_\alpha(e_j)\, f_{e_j,i}$$

Questionnaire

- 13 Calibration Questions
  - ➢ Based on 4 past projects performed by Van Oord
  - ➢ Projects were anonymized
  - ➢ Relevant details of each project were provided
- 12 Target Questions (regarding variables of interest)
  - ➢ Concern delays in the supply of required components before the loading operation can start
  - ➢ Support projects with the following characteristics
    - Location: North Sea
    - > 50 Wind Turbines
    - > 150 NM distance from manufacturer

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Questionnaire – Calibration question

Components	Monopiles (MPs)
Installation port	Birkenhead, Liverpool
Manufacturer location	Rostock
Distance of installation port from manufacturer	~1150 NM
Transportation method to installation port	Shipped (vessel speed 15 kn)
Estimated transportation duration to installation port	~ 75 h
Number of trips from manufacturer	8
Buffer stock at installation port at the commencement of the installation operation	20
Transportation from installation port to OWF site	Tugs towed floating MPs to the installation vessel on-site

CQ: Occasionally, the required MPs were not available while the vessel was on-site ready to start the installation, what do you believe was the **maximum** registered delay (i.e. waiting time), until the required MPs were available?

5% (*surprised if true value is less than*)	**50%** (*best judgment*)	**95%** (*surprised if true value is more than*)

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Questionnaire – Target questions

- Relative frequency of unavailability of different components
- Waiting time distribution for different components

TQ: If the required MPs are not ready for loading while the transportation vessel is in port, what would you expect to be the delay (i.e. waiting time) until the required MPs are available for loading?

5% (*surprised if true value is less than)*	**50%** *(best judgment)*	**95%** (*surprised if true value is more than)*

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Participants of the study

- Diverse group of 11 experts from different companies and 4 different countries (NL, DE, BE, GB)
- Experts’ experience in the offshore wind field ranged from 3 to 11 years
- Expert judgments elicited during a workshop and individual interviews
- Elicitation sessions took place from 12 July – 15 August 2017

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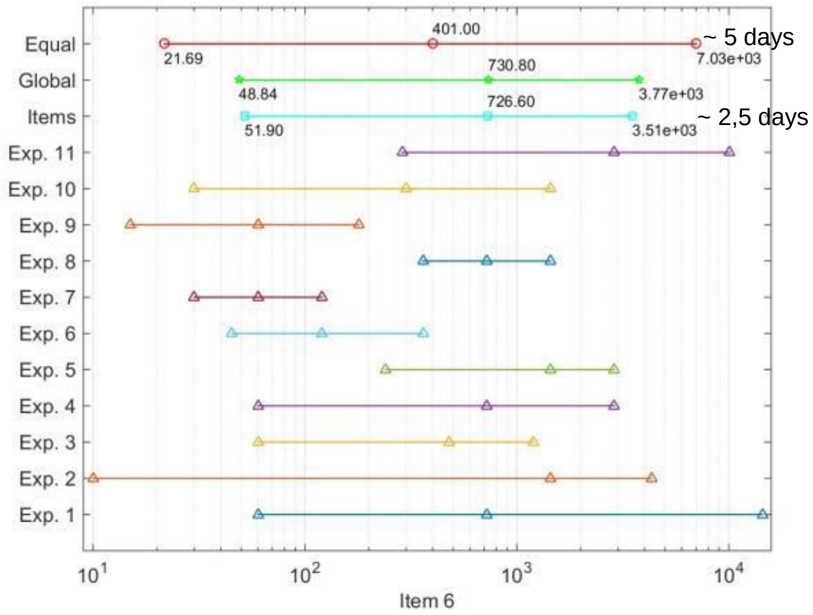
Obtained distributions

- Relative frequency of occurrence
- Waiting time until components ready for loading
- Small alterations for different components:
  - Monopiles
  - Transition Pieces
  - Towers
  - Blades
  - Nacelles
  - Infield cable



Waiting time (in minutes) because required Towers not available for loading

Test Case

Details	
Wind Turbines:	150
Location:	North Sea
Starting Date:	1 June 2015
Installation operations:	Support structures, Wind turbines, Cable and Offshore Substation
Initial stock in the commencement of project	10 units of each component (MPs, TPs, Towers, Nacelles, Rotors)

- Simulated using the modified ECN Install and sampling from obtained waiting time distributions
- 3 Cases:
  - Base Case (excl. supply disruptions)
  - Neutral Case (incl. supply disruptions with “average” prob. of occurrence)
  - Pessimistic Case (incl. supply disruptions with high prob. of occurrence)

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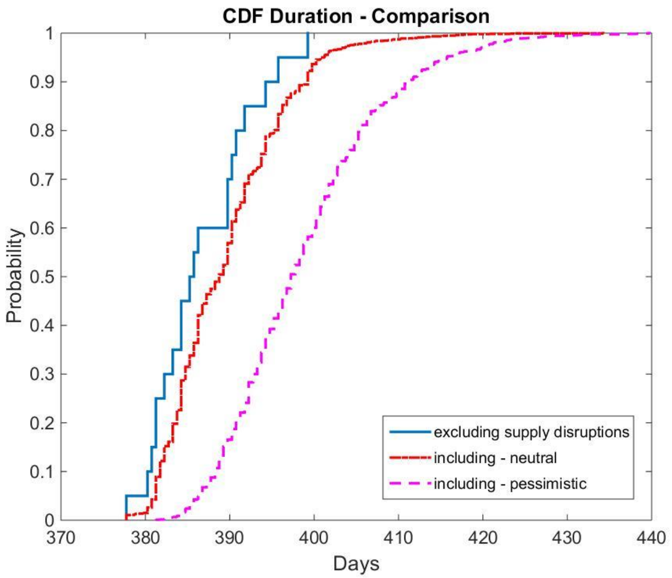
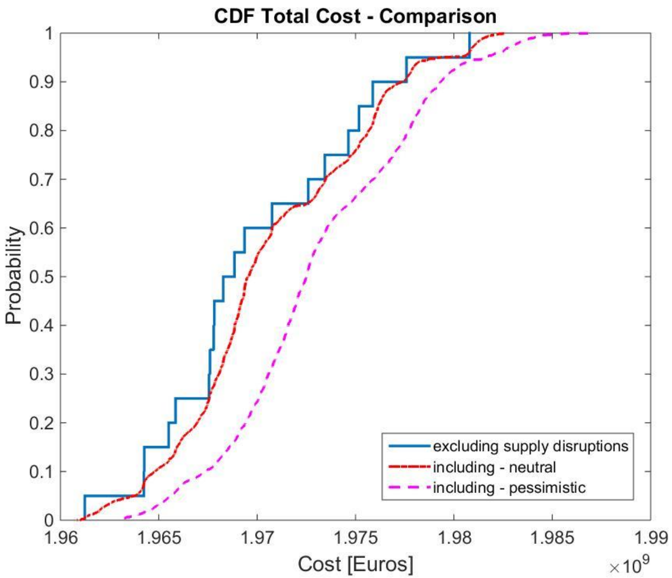
Preliminary results

- CDFs of Duration and Cost for different cases





<u>P80 Duration</u>
~5 days (neutral vs excl. risk)
~14,5 days (pessimistic vs excl. risk)

<u>P80 Total Cost</u>
~1,03 ME (neutral vs excl. risk)
~3,06 ME (pessimistic vs excl. risk)

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Preliminary conclusions

- In the absence of sufficient data, expert judgments can be used to quantify risk of supply disruptions
- Disregarding supply disruptions from the estimated duration and cost may cause significant schedule & budget overrun
- Including supply disruptions in the estimates assists in comparing scenarios & making optimal decisions regarding:
  - Schedule of installation
  - Buffer stock
  - Selection of vessels and installation port
- Obtained distributions can be used for coming projects but were wide; to improve this:
  - Elicitation of expert opinions for a specific project
  - Include dependence with respect to project characteristics

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Thank you very much!

Back up slides

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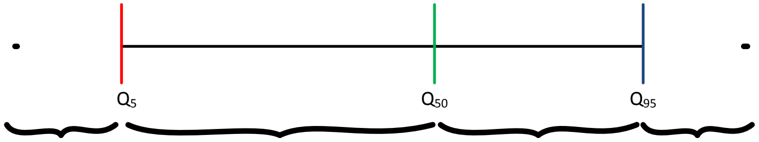
Percentiles explanation

- Experts are asked to provide the 5th, 50th and 95th percentile



5 %-tile **Q_5**	Assuming 100 realizations of the described event, only 5 realizations would have value **smaller** than the provided value **Q_5**. *Expert will be surprised if true value is less than Q_5*
50 %-tile **Q_{50} (median)**	Assuming 100 realizations of the described event, 50 realizations would have value smaller than the provided value **Q_{50}**. *This value can be seen as the expert's best judgment*.
95 %-tile **Q_{95}**	Assuming 100 realizations of the described event, only 5 realizations would have value **larger** than the provided value **Q_{95}**. *Expert will be surprised if true value is larger than Q_{95}*.

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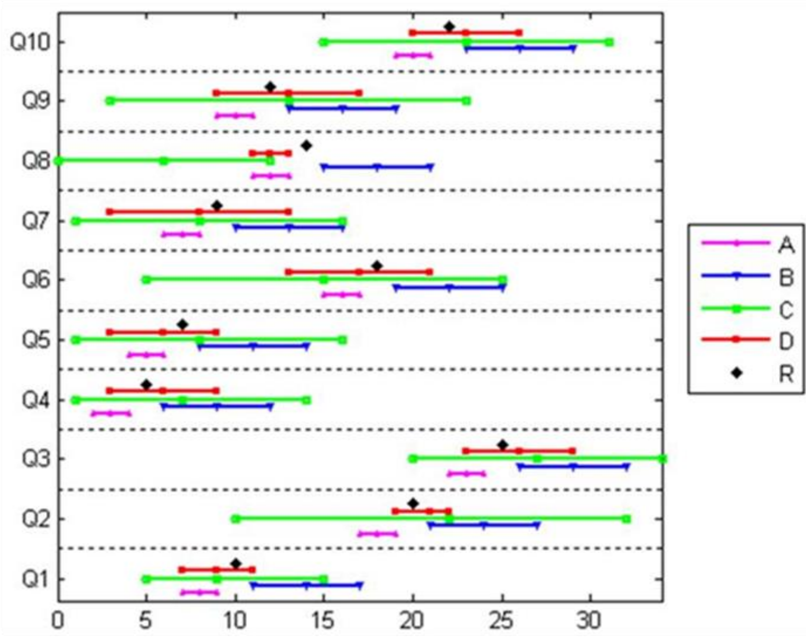
Good uncertainty assessors

- Statistically accurate and informative
- Expert A: informative but always underestimates
- Expert B: less informative but always overestimates
- Expert C: statistically accurate
- Expert D: statistically accurate and informative



- Expert C and D are better in assessing uncertainty! So we want to assign more weight to their opinions

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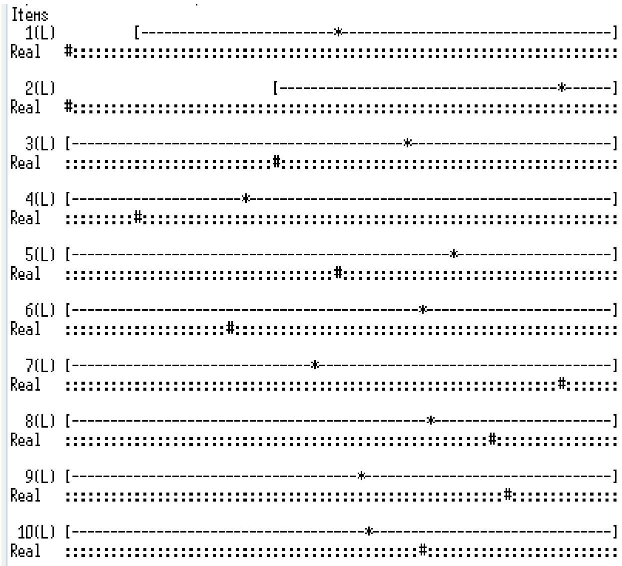
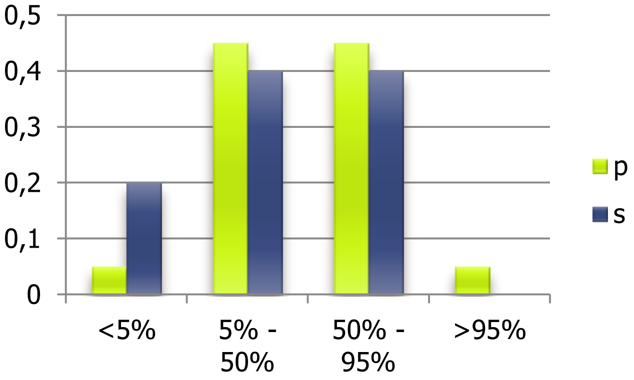
SEJ – Calibration score C(e)

- Based on a sufficient number of calibration questions
- Measure of statistical accuracy of the expert (A statistically accurate expert is the expert whose assessments capture the true values of the seed questions with the long run correct relative frequencies)





p: theoretical distribution

s_e: distribution of expert e

C(e) = 0.3006

Calibration Score

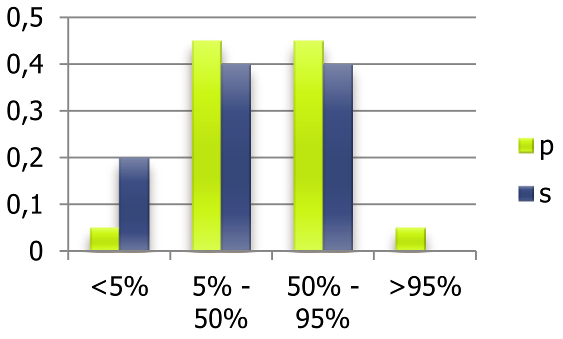
- It is given by:

$$C(e) = 1 - \chi^2_3(2NI(s;p))$$

Value of cumulative chi square distribution with n-1 degrees of freedom

where relative information measure the discrepancy between s and p:

$$I(s;p) = \sum_1^4 s_i \log\left(\frac{s_i}{p_i}\right)$$



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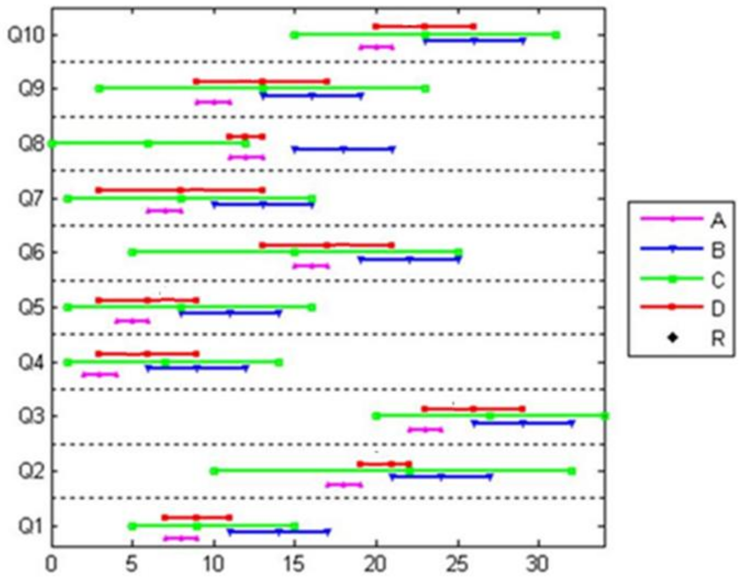
Information Score

- Information is measured w.r.t. a background measure (Uniform or Log-uniform)

- Information is the degree to which the expert's distributions are **concentrated**

- In the example expert A has higher information score



Information Score

- Measure of difference between experts' distribution and uniform (or log-uniform) distribution
- Shows the degree to which the experts' distributions are concentrated. High value: expert is adding "a large amount of information" to the background distribution
- Define intrinsic range $[x_0, x_{n+1}]$ for every variable with k% overshoot rule (typically k% = 0,1)

$$\begin{aligned} x_0 &= l - k\% \times [h - l] \\ x_{n+1} &= h + k\% \times [h - l] \end{aligned}$$

- On a variable *i*

$$I(e_i) = \ln(x_{n+1} - x_0) + \sum_{j=0}^{n} p_j \ln\left(\frac{p_j}{x_{j+1} - x_j}\right)$$

$$I(e) = \frac{1}{N}\sum_{i=1}^{N} I(f_{e,i}; g_i) = \frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{4} p_{i,j} log\left(\frac{p_{i,j}}{g_{i,j}}\right)$$

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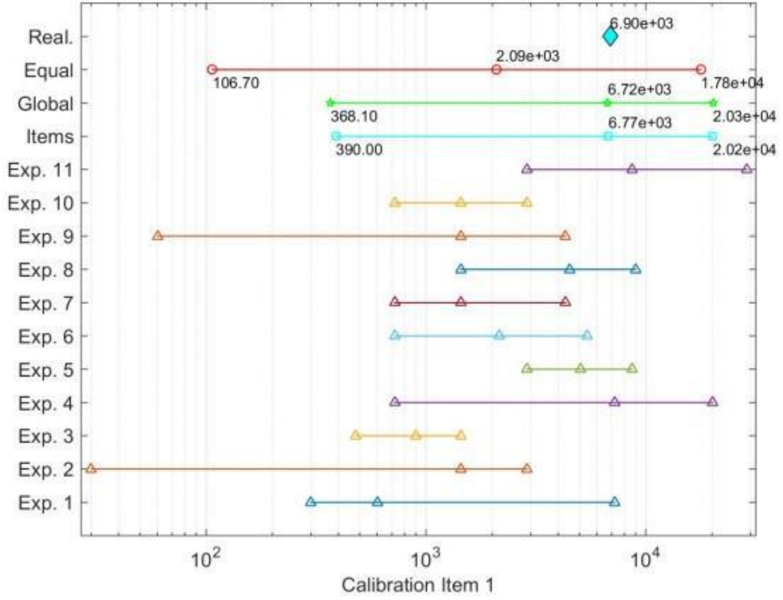
Calibration question example



- Maximum registered delay (in min) because required MPs were not available

Variables of interest summary

Component \ Elicited variable	Relative frequency of occurrence			Waiting time (h)		
	5th	50th	95th	5th	50th	95th
Blades						
Nacelles						
Transition pieces						
Towers						
Monopiles						
Cable						

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