Probabilistic decision support for offshore wind operations:

A Bayesian Network approach to include the dependence of the installation activities

PSAM 14 conference

18 September 2018, UCLA Meyer & Renee Luskin Conference Center

Georgios Leontaris
Oswaldo Morales-Nápoles
Rogier Wolfert

TU Delft

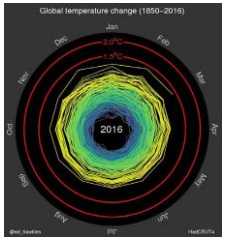
EUROS
Excellence in Uncertainty Reduction of Offshore wind Systems

Outline

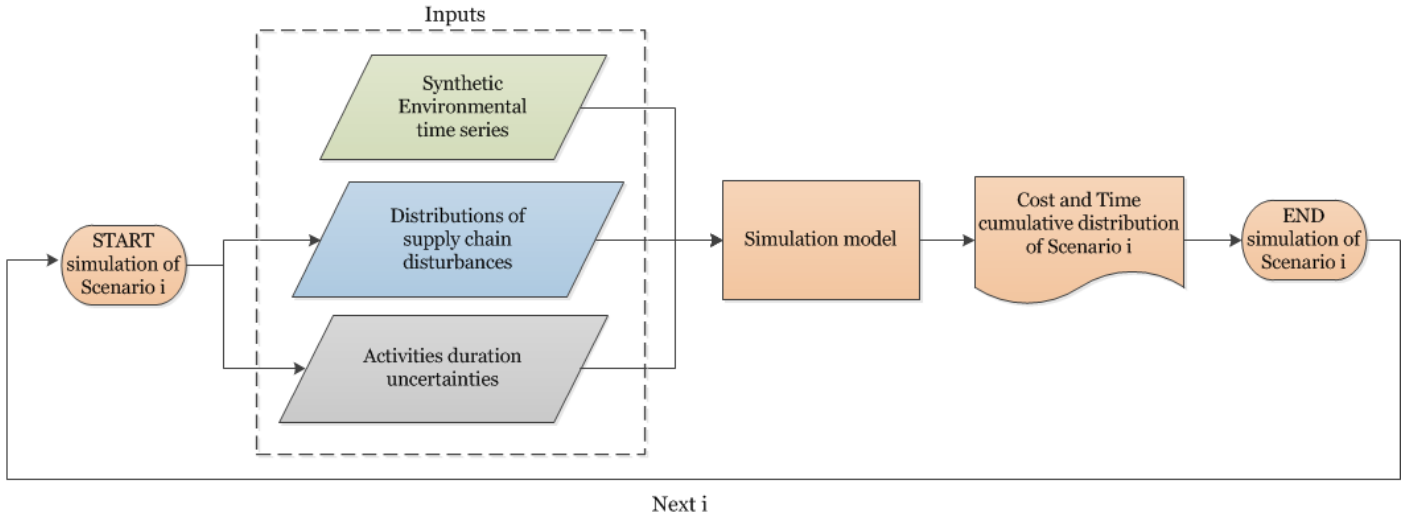
- Introduction
- Motivation
- Methodology
- Test case
- Results
- Conclusions

Introduction

- Transition towards renewable energy sources is needed
- Offshore wind energy is considered one of the most promising
- Recently started becoming financially competitive
- High existing costs which grow as we move farther offshore
- Need for improvement of the management of installation process



Probabilistic scheduling model



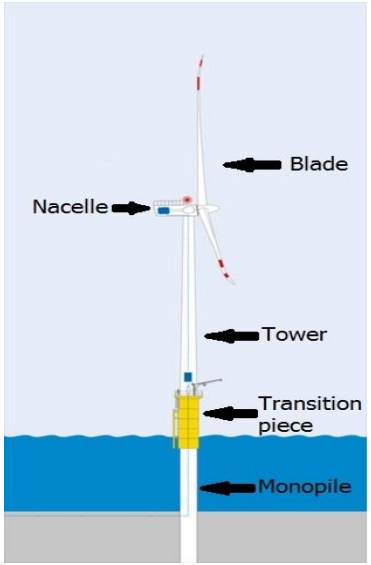
- Generate realistic synthetic time series (Copulas)
- Obtain distributions of Supply chain disruptions (SEJ)
- Describe dependence of installation durations (NPBN)

Motivation

- Uncertainty regarding **activities' duration** is often overlooked
- Some cases: use triangular or normal distributions
- Always assumed to be independent
- Investigation of a method to describe the dependence between activities duration
- Explore the impact of neglecting multivariate uncertainty

Approach

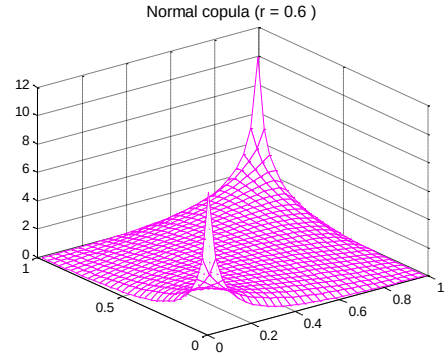
- Historical data provided by Van Oord
  - Installation of 150 WTGs in the North Sea
  - 2 different installation vessels
- Diagnosis for Dependence (copulas)
  - Semi-correlations
  - Blanket tests
- Building the NPBN model
- Simulation of test case

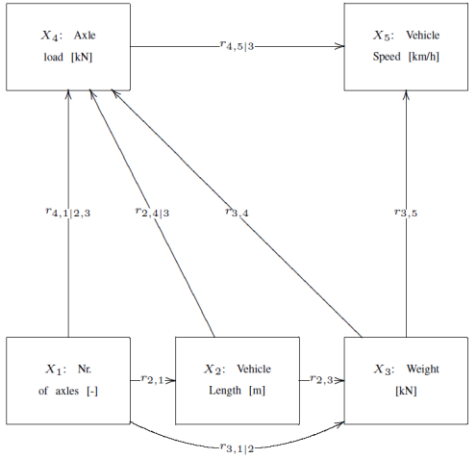


NPBN description

$$f_{X_1,\ldots,X_n} = \prod_{i=1}^{n} f_{X_i|Pa(X_i)}$$

- BNs Directed Acyclic Graph
- Nodes represent random variables
- Provide language for conditional (in)dependence
- Copulas realizing (conditional) rank correlations in the arcs



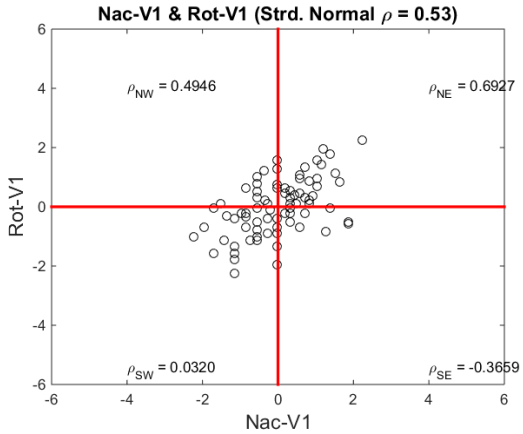


TU Delft

Dependence Diagnosis

- Cramer-von-Mises statistic S_n for copulas with different tail dependence
- Semi-correlations to investigate asymmetries
- Formal P-value test did not distinguish between models as valid

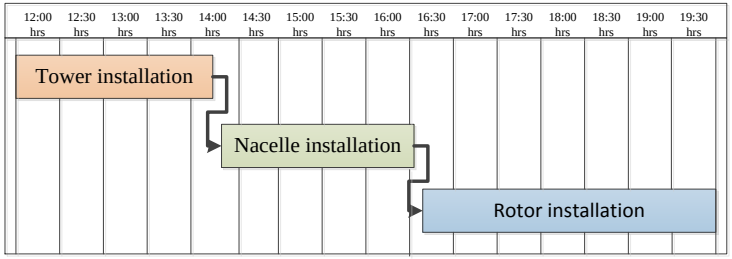
$$S_n = \sum \{C_n(\boldsymbol{u}) - C_{\theta_n}(\boldsymbol{u})\}^2$$

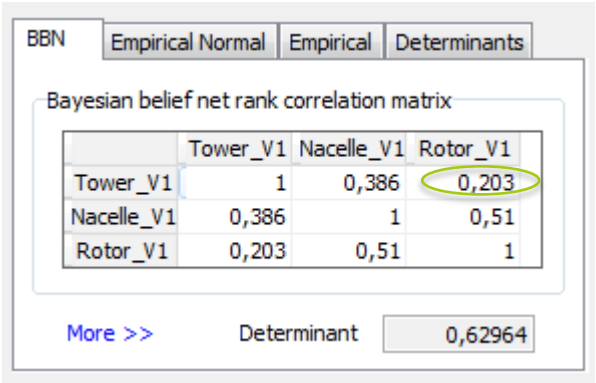


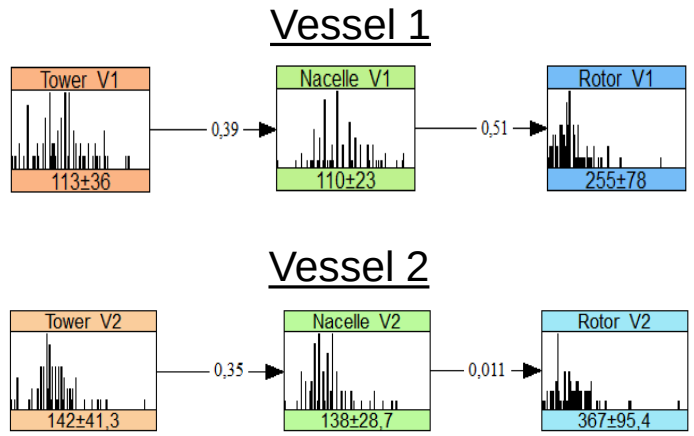
	ρ	ρ_{NE}	ρ_{SE}	ρ_{SW}	ρ_{NW}	S_{gauss}	S_{gumbel}	$S_{clayton}$
Twr – Nac_V1	0,40	0,226	-0,066	-0,233	-0,575	0,4531	**0,396**	0,674
Twr – Rot_V1	0,28	0,369	0,018	-0,291	-0,067	0,6428	**0,586**	0,864
Nac – Rot_V1	0,53	0,692	-0,365	0,032	0,494	**0,2972**	0,3367	0,357

NPBN models for installation activities

- Diagnosis → Gaussian copula valid assumption
- Models for 2 vessels
- 3 sequential installation activities





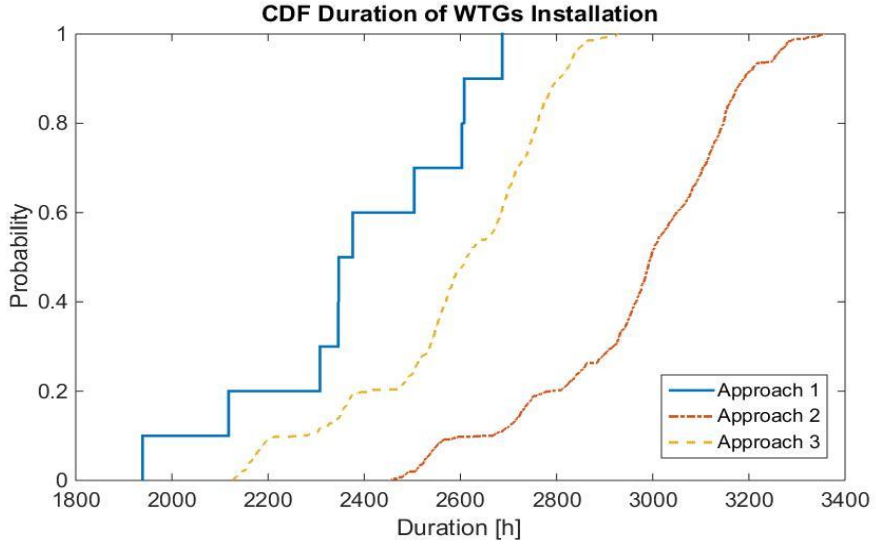


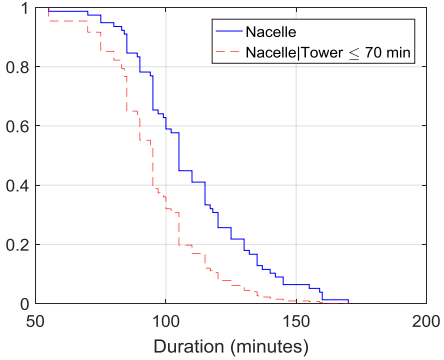
Details of test case

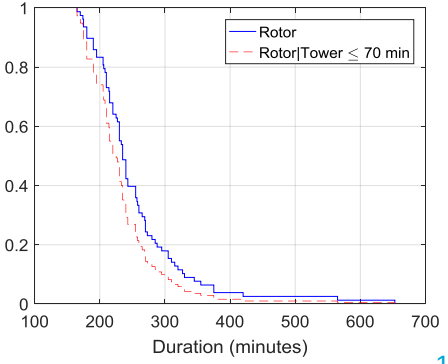
Details	Value							
Number of WTGs	150							
Number of vessels	2 (vessel V1 and V2)							
Location	North Sea							
Environmental time series	10 years of measurements for H_s and U_W							
Environmental limits	$H_s = 1.5\,m$ and $U_W = 8\,m/s$							
Approach 1 (independent deterministic durations)	Tower_V1 = 115 min Nacelle_V1 = 105 min Rotor_V1 = 230 min				Tower_V2 = 125 min Nacelle_V2 = 125 min Rotor_V2 = 305 min			
Approach 2 (independent stochastic durations)	Triangular distribution for V1 with parameters				Triangular distribution for V2 with parameters			
		a	b	c		a	b	c
	Tower	45	115	226	Tower	65	125	310
	Nacelle	55	105	170	Nacelle	85	125	255
	Rotor	165	230	653	Rotor	245	305	795
Approach 3 (dependent stochastic durations)	Developed BN model for V1				Developed BN model for V2			

Results

- *Approach 1 (constant durations)* vs *Approach 3 (NPBNs)* difference equal to ≈200 hours (P80)
- NPBN model characterized better uncertainty compared to *Approach 2 (Trian. distr.)*







Conclusions

- NPBN with serial connection is a realistic representation of the sequential nature of WTGs installation process
- NPBN model characterized better uncertainty compared to *Approach 2 (independent stochastic)*
- Possible to assist decision makers in planning of the OWFs installation
- An extended model with more installation activities may have potential for significant cost reduction (of millions of Euros as it was shown for this particular application)
- Similar model could be used in execution phase to support decision making for project control

TU Delft

Thank you!

Back up slides

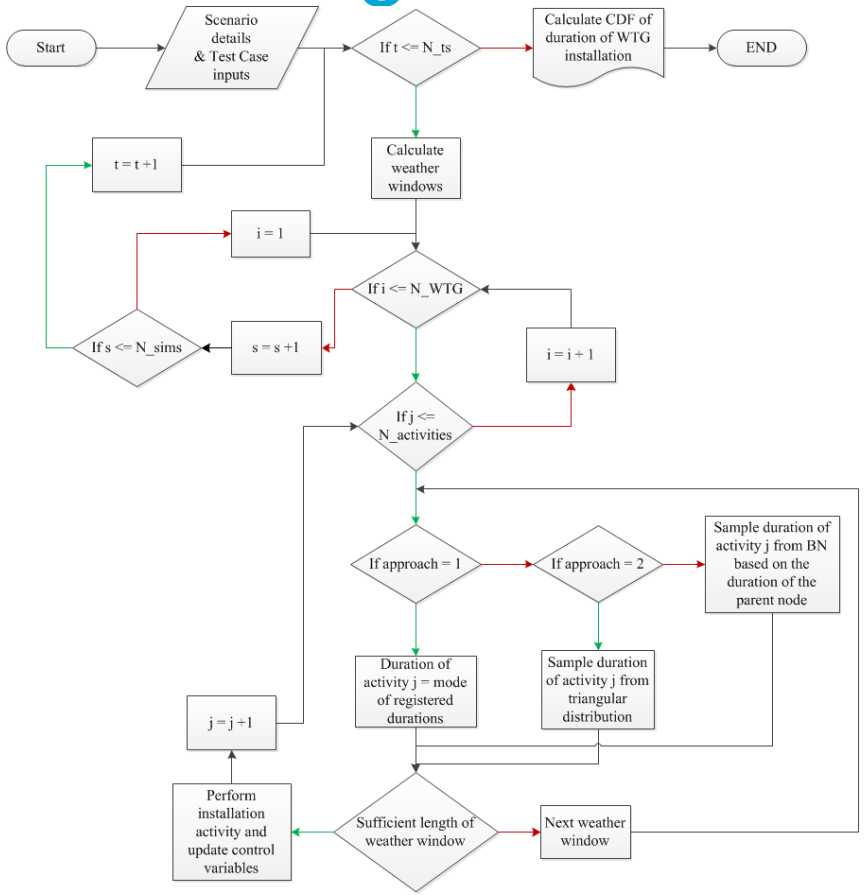
Model validation

- Empirical and BN rank correlations were similar
- Determinants of Empirical, Normal and BN correlation matrices

	Empirical rank correlation			BN rank correlation		
	Twr_V1	Nac_V1	Rot_V1	Twr_V1	Nac_V1	Rtr_V1
Twr_V1	1	0.403	0.285	1	0.386	0.203
Nac_V1	0.403	1	0.517	0.386	1	0.51
Rot_V1	0.285	0.517	1	0.203	0.51	1

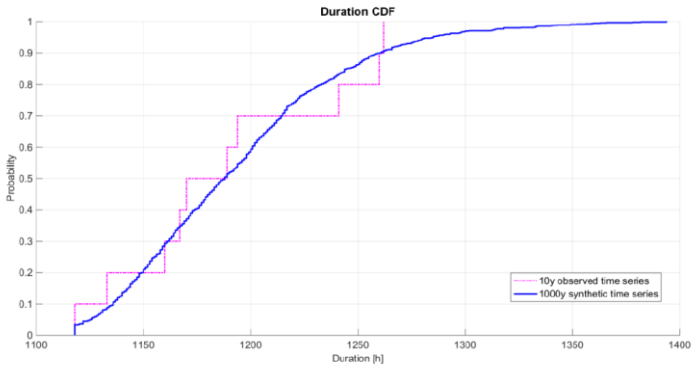
	Model for V1	Model for V2
DER	0.60777	0.88103
DNR	0.62483	0.87358
DBN	0.62964	0.87514

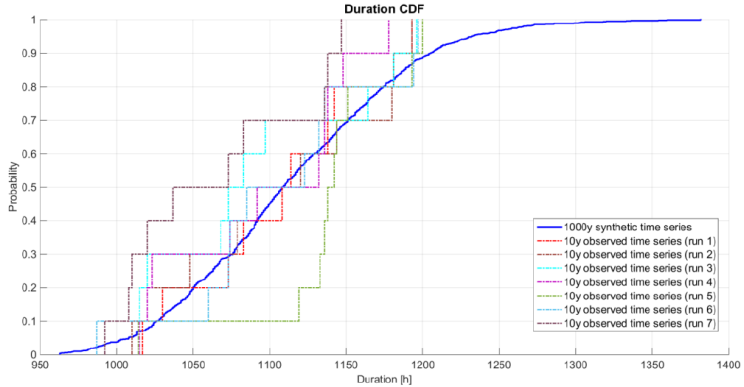
Simulation Algorithm



Findings weather risk

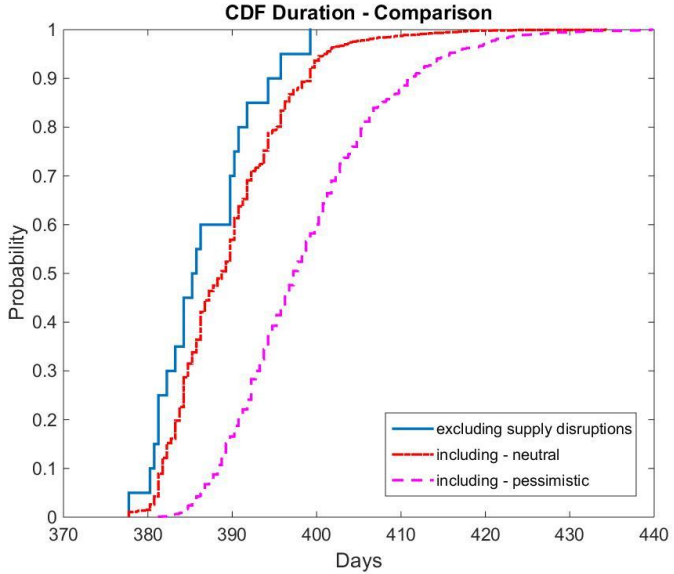
- Crucial to produce realistic synthetic time series in order to obtain accurate and reliable estimates when different uncertainties are taken into account
- Stochastic simulation models can help in identifying the impact of different uncertainties

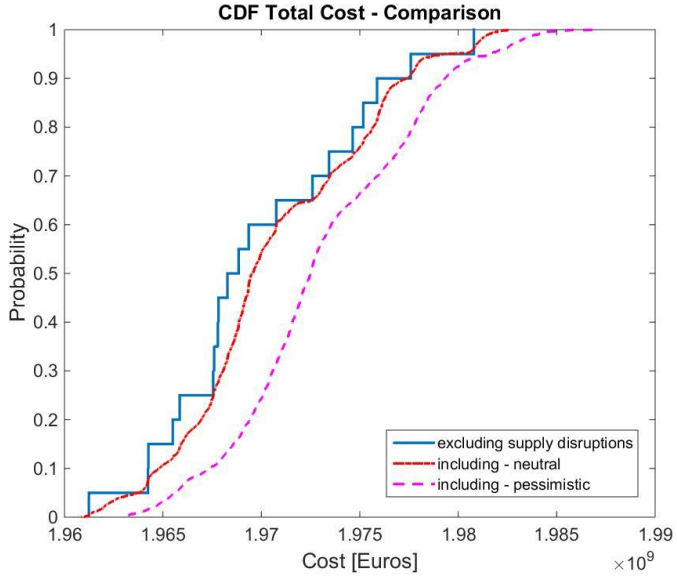




Preliminary results supply risk

- CDFs of Duration and Cost for different cases





P80 Duration

~5 days (neutral vs excl. risk)

~14,5 days (pessimistic vs excl. risk)

P80 Total Cost

~1,03 ME (neutral vs excl. risk)

~3,06 ME (pessimistic vs excl. risk)