SINTEF

A METAHEURISTIC SOLUTION METHOD FOR OPTIMIZING VESSEL FLEET SIZE AND MIX FOR MAINTENANCE OPERATIONS AT OFFSHORE WIND FARMS UNDER UNCERTAINTY

EERA DEEPWIND'2017, TRONDHEIM, 18 JANUARY 2017

Elin E. Halvorsen-Weare[1], Inge Norstad[1],
Magnus Stålhane[2], Lars Magne Nonås[1]

[1]Department of Maritime, SINTEF Ocean
[2]Department of Industrial Economics and Technology Management, NTNU

Outline

1 Setting the scene

2 Vessel fleet optimization model

3 Solution method

4 Application on a reference case

5 Summary

SINTEF

Outline

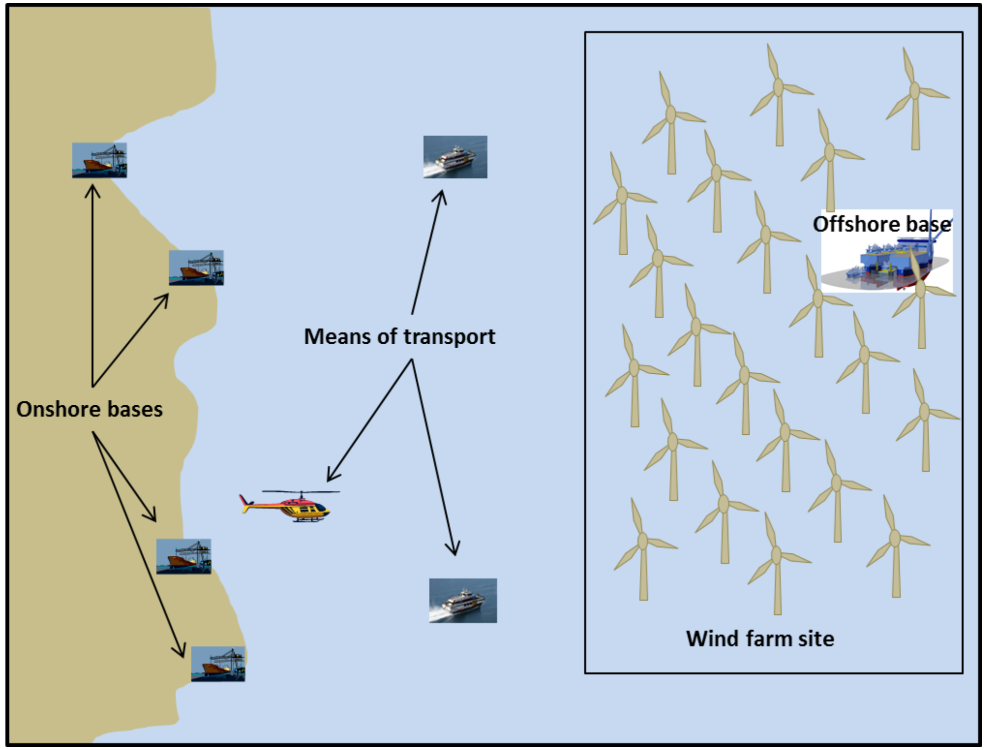
1. Setting the scene
2. Vessel fleet optimization model
3. Solution method
4. Application on a reference case
5. Summary

SINTEF

Deep sea offshore wind O&M logistics - Challenges

- Large number of turbines
  - Many maintenance tasks
- Large distances
- Marine operations
- Accessibility to wind farm and turbines
  - Weather restrictions

O&M at offshore wind farms



Focus on the maritime transportation and logistic challenges:

- Need to execute maintenance tasks at wind turbines
  - Preventive maintenance tasks
    - Scheduled tasks
  - Corrective maintenance tasks
    - Component failure requiring repair or replacement
- Need to transport technicians, spare parts etc. from a maintenance base to the turbines
  - From which maintenance ports/bases?
  - By which vessel resources?

SINTEF

Which vessel resources are most promising for a given offshore wind farm?

Evaluating all possible vessel fleets is impractical and time consuming, and often impossible

10 vessel types, 0-3 vessels each → $2^{20} \approx 1$ million combinations

Outline

1 Setting the scene

2 Vessel fleet optimization model

3 Solution method

4 Application on a reference case

5 Summary

SINTEF

Vessel fleet optimization model for O&M

Main idea:

- Create a decision support tool for selecting the best logistical resources, i.e. vessels, infrastructure and related resources, and the best deployment of these resources to execute maintenance tasks at offshore wind farms

Why?

- Many options for vessels and infrastructure configurations, maintenance strategies, and site specific considerations makes it difficult to get a good overview without strategic analytical tools to evaluate the solution space
- Offshore wind farms at deep sea locations creates the need to develop new technology and logistics strategies, that need to be evaluated from an economical perspective

Development of vessel fleet optimization model

Vessel fleet optimization model – developed through various research projects:

NOWITECH (2010 – 2017)

Initialization of development

Development of stochastic mathematical model for vessel fleet optimization

FAROFF (2012 – 2013)

Developed first prototype of vessel fleet optimization model

- Deterministic mathematical model for vessel fleet optimization

LEANWIND (2013 – 2017)

Development of heuristic solver for the stochastic vessel fleet optimization model

Stochastic mathematical optimization model

- Pattern-based mathematical formulation
  - Candidate patterns generated for vessel and base combinations
  - Based on vessel characteristics and compatibility with maintenance tasks
- Patterns are input to the mathematical model
  - Two-stage stochastic model formulation
- Stochastic parameters
  - Weather conditions (wind and wave)
  - Corrective maintenance tasks (generated based on failure rates)

Stochastic mathematical optimization model

- Variables:
  - Which vessels to use
    - Short-term or long-term charter?
  - Which maintenance patterns vessels should execute
  - Which maintenance ports/bases to use
- Objective: Minimize total cost
  - Time charter costs
  - Port/base costs
  - Fuel costs – and other voyage related costs
  - Downtime cost
- All maintenance tasks should be executed within the planning horizon, or they are given a penalty cost

SINTEF

Stochastic mathematical optimization model

$$\min \sum_{k \in K} C_k^F \delta_k + \sum_{k \in K} \sum_{v \in V_k} C_v^F x_{kv}^L + \sum_{k \in K} \sum_{v \in V_k} \sum_{t \in P^T} C_{vl}^F x_{kvt}^S +$$

$$\sum_{s \in \mathcal{S}} P_s \Bigg[\sum_{v \in V} \sum_{i \in N^C \cap N_v} \sum_{j \in N_{is}^C} \sum_{p \in P_{vijs}} C_{ijps}^D y_{vijps} + \sum_{k \in K} \sum_{v \in V_k} \sum_{w \in W_{kv}} \sum_{i \in N^P \cap N_v} \sum_{p \in P_{kvws}} C_{ips}^D A_{iw} \lambda_{kvwps} +$$

$$\sum_{k \in K} \sum_{v \in V_k} \sum_{w \in W_{kv}} \sum_{p \in P_{kvws}} C_{kvwps} \lambda_{kvwps} + \sum_{i \in N^P} C_i^P z_{is} + \sum_{i \in N^C} \sum_{j \in N_{is}^C} C_i^P z_{ijs} \Bigg]. \tag{1}$$

Objective function

SINTEF

Stochastic mathematical optimization model

$$x^L_{kv} + x^S_{kvt} \leq Q_{kv}\delta_k, \qquad k \in K, v \in V_k, t \in P^T, \qquad (2)$$

$$\delta_{k1} + \delta_{k2} \leq 1, \qquad (k1, k2) \in K^C, \qquad (3)$$

$$\delta_k \geq E_k, \qquad k \in K, \qquad (4)$$

$$x^L_{kv} \geq E_{kv}, \qquad k \in K, v \in V_k, \qquad (5)$$

$$\sum_{k \in K} x^S_{kvt} \leq Q^{MX}_{vt}, \qquad v \in V, t \in P^T, \qquad (6)$$

$$\delta_k \in \{0, 1\}, \qquad k \in K, \qquad (7)$$

$$x^L_{kv} \in Z^+, \qquad k \in K, v \in V_k, \qquad (8)$$

$$x^S_{kvt} \in Z^+, \qquad k \in K, v \in V_k, t \in P^T. \qquad (9)$$

First stage constraints

Stochastic mathematical optimization model

$$\sum_{k\in K}\sum_{v\in V_k\cap V_i}\sum_{w\in W_{kv}}\sum_{p\in P_{kvws}} A_{iw}\lambda_{kvwps} + z_{is} = A_i, \quad i\in N^P, s\in \mathcal{S}, \quad (10)$$

$$\sum_{v\in V_i}\sum_{p\in P_{vijs}} y_{vijps} + z_{ijs} = 1, \quad i\in N^C, s\in\mathcal{S}, j\in N^C_{is}, \quad (11)$$

$$\sum_{k\in K}\sum_{w\in W_{kv}} A_{iw}\lambda_{kvwps} - \sum_{j\in N^C_{is}} y_{vijps} = 0, \quad v\in V, i\in N^C\cap N_v, p\in P_v, s\in\mathcal{S}, \quad (12)$$

$$\sum_{w\in W_{kv}} \lambda_{kvwps} \le x^L_{kv} + x^S_{kvt}, \quad k\in K, v\in V_k, p\in P_v, t\in P^T|p\in t, s\in\mathcal{S}, \quad (13)$$

$$\sum_{v\in V}\sum_{w\in W_{kv}} M_v\lambda_{kvwps} \le M_k\delta_k, \quad k\in K, p\in P, s\in\mathcal{S}, \quad (14)$$

$$\lambda_{kvwps}\in Z^+, \quad k\in K, v\in V_k, w\in W_{kv}, s\in\mathcal{S}, p\in P_{kvws}, \quad (15)$$

$$y_{vijps}\in\{0,1\}, \quad v\in V, i\in N^C\cap N_v, s\in\mathcal{S}, j\in N^C_{is}, p\in P_{vijs}, \quad (16)$$

$$z_{is}\in Z^+, \quad i\in N^P, s\in\mathcal{S}, \quad (17)$$

$$z_{ijs}\in\{0,1\}, \quad i\in N^C, s\in\mathcal{S}, j\in N^C_{is}. \quad (18)$$

Second stage constraints

Outline

1 Setting the scene

2 Vessel fleet optimization model

3 Solution method

4 Application on a reference case

5 Summary

Metaheuristic solution framework

Greedy randomized adaptive search procedure – GRASP

1. Construct an initial feasible solution to the problem by a greedy randomized algorithm
2. Improve the initial feasible solution by a local search procedure
3. Continue until stopping criterion is met

All candidate solutions are evaluated by a simulation procedure taking into account uncertainty in weather conditions and corrective maintenance tasks

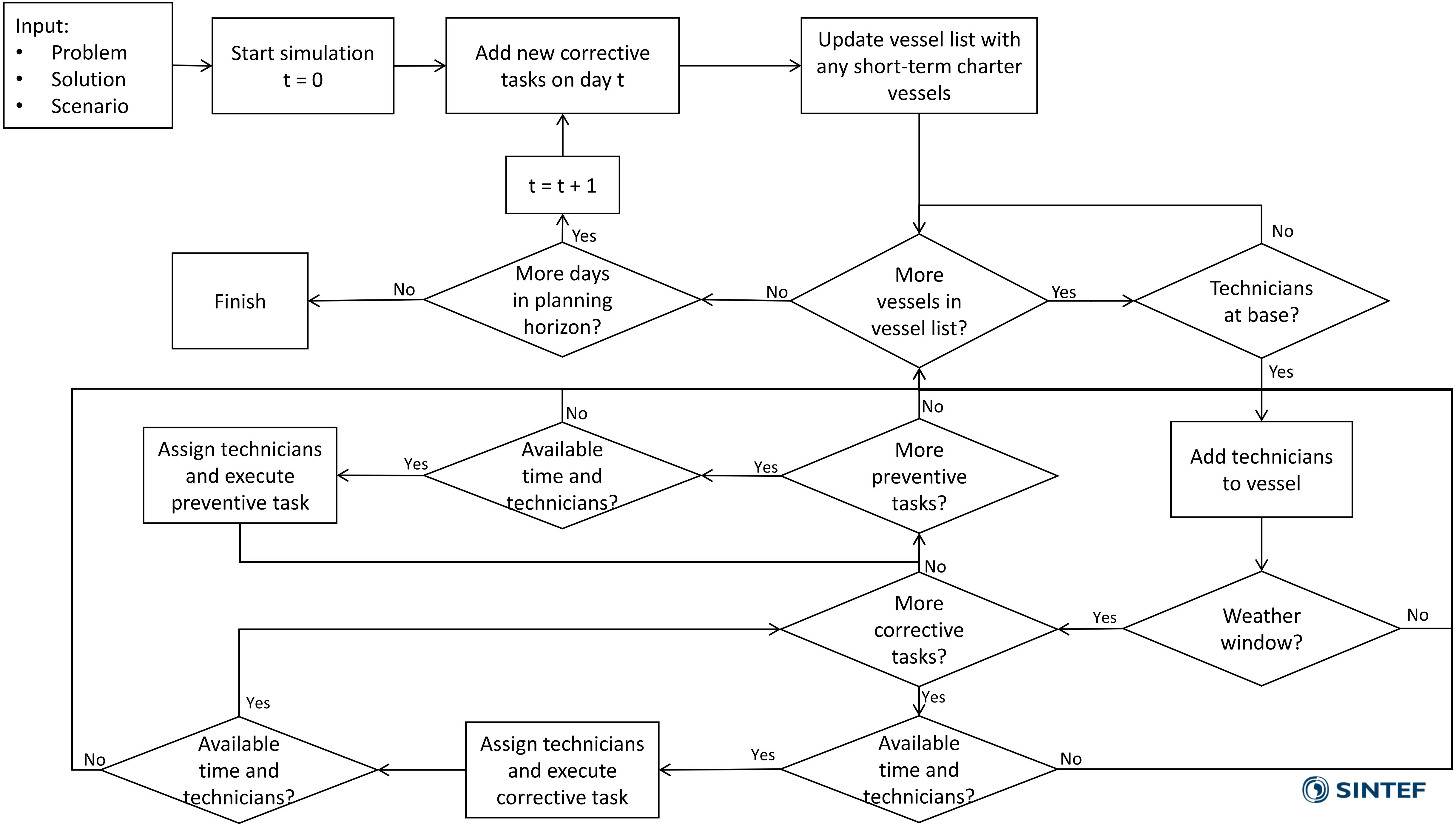
Local search algorithm

Explore neighborhood solutions to an initial solution:

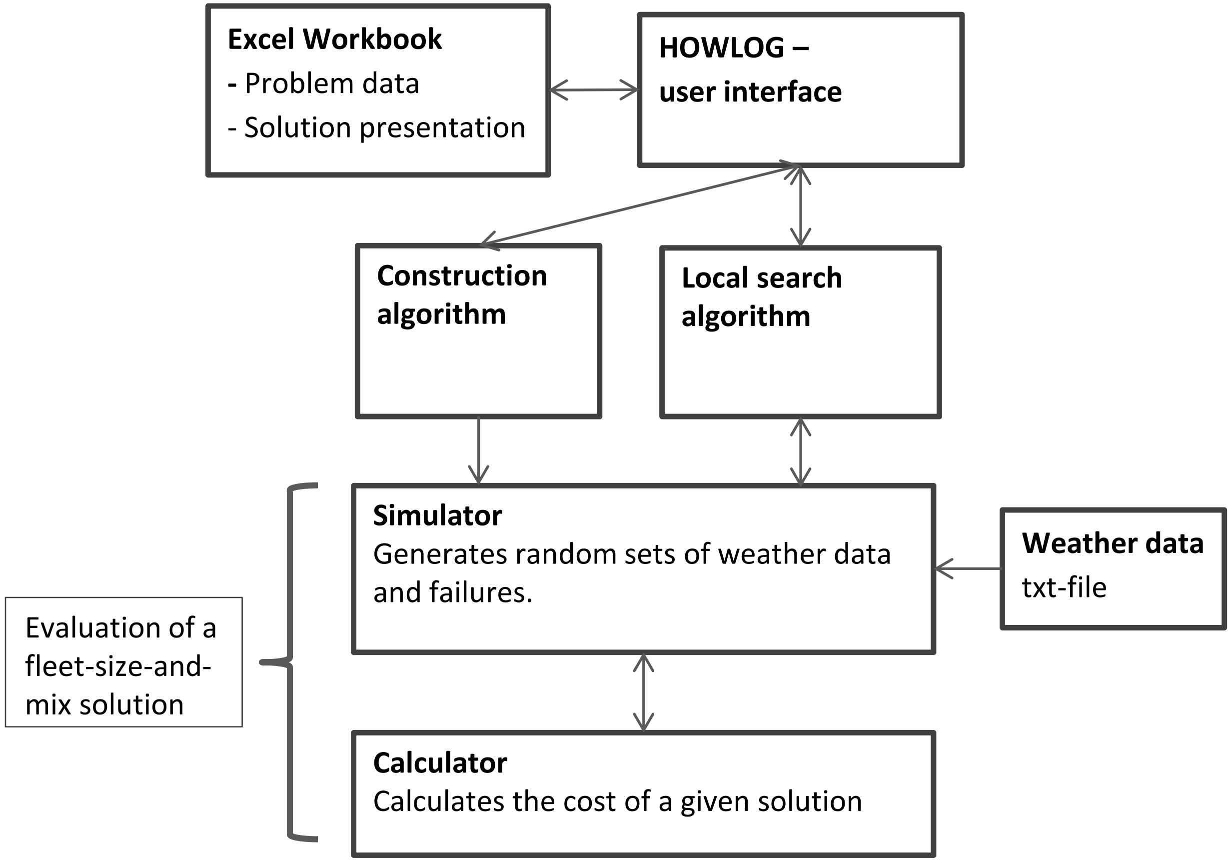
- Add vessel long-term
- Remove vessel long-term
- Add vessel short-term
- Remove vessel short-term
- Remove base
- Swap bases
- Swap vessels long-term
- Swap vessels short-term

Evaluation of candidate solutions

- Scenario generator
  - Generates a number of weather data sets and corrective maintenance tasks sets
- Calculator
  - Calculates the objective function value of a solution for a given weather data and corrective maintenance task set

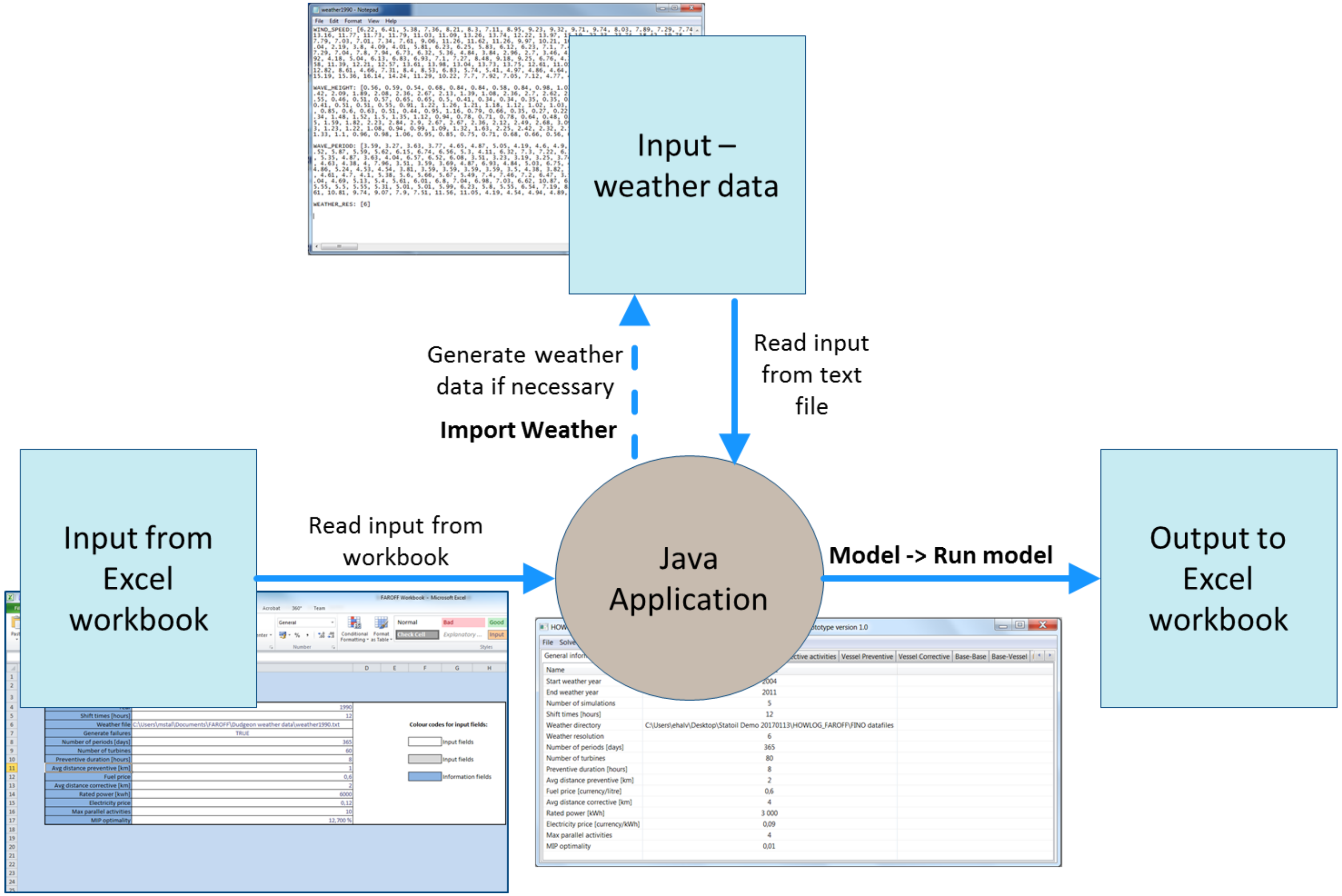

Input:
• Problem
• Solution
• Scenario
Start simulation
t = 0
Add new corrective
tasks on day t
Update vessel list with
any short-term charter
vessels
t = t + 1
Yes
No
Finish
No
More days
in planning
horizon?
No
More
vessels in
vessel list?
Yes
Technicians
at base?
Yes
No
No
Assign technicians
and execute
preventive task
Yes
Available
time and
technicians?
Yes
More
preventive
tasks?
Add technicians
to vessel
No
More
corrective
tasks?
Yes
Weather
window?
No
Yes
Yes
Available
time and
technicians?
No
Assign technicians
and execute
corrective task
Yes
Available
time and
technicians?
No
SINTEF

Overview metaheuristic framework



SINTEF

Configuration of vessel fleet optimization tool



Outline

1 Setting the scene

2 Vessel fleet optimization model

3 Solution method

4 Application on a reference case

5 Summary

Application on a reference case

(Sperstad et al. 2016)

- Wind farm with 80 3MW turbines
- 50 km distance to onshore maintenance base
- One type of preventive maintenance: 60 hours work x 80 turbines
- Three types of corrective maintenance: Failure rates 7.5, 3 and 0.825
- Weather data from FINO1 metocean platform
- Electricity price 90 GBP/MWh

Available vessel resources

Vessel type name	Hs limit [m]	Transfer speed [knots]	Day rate [GBP]	Technician transfer space	Access time [min]	# available vessels
Crew transfer vessel (CTV)	1.5	20	1 750	12	15	5
Surface effect ship (SES)	2.0	35	5 000	12	15	5
Small accommodation vessel (SAV)	2.0	20	12 500	12	15	1
Mini mother vessel (MM)	2.5	14	25 000	16	30	1
Daughter vessel (DM)	1.2	16	N/A	6	15	2

Results

	GRASP	EXACT
Vessel fleet	**2 SES**	**2 SES**
Expected total cost	13 438 089	13 318 186
Vessel cost	3 650 000	3 650 000
Voyage cost	2 098 533	2 016 700
Downtime cost	7 689 544	7 651 486
Electricity based availability	92.96 %	93.02 %
Computational time [s]	144	7 961

GRASP method has been implemented in Java, number of simulations on each candidate solution was 30. EXACT method has been implemented in the Mosel language and solved by FICO™ Xpress, number of scenarios was 5, and optimality gap was set to 1.0%.

Application areas

- Offshore wind farm developers
  - Which are the optimal maintenance vessel resources?
  - Which are the optimal maintenance ports/bases and what type of characteristics should they have?
  - When should the maintenance activities be scheduled?

- Maintenance vessel developers and innovators
  - Cost/benefit analysis for evaluating/choosing among existing vessels
  - Early phase feedback for design of new vessels

- Maintenance concept developers and innovators
  - Cost/benefit analysis of new concepts and the potential effects on the logistic systems

Outline

1 Setting the scene

2 Vessel fleet optimization model

3 Solution method

4 Application on a reference case

5 Summary

SINTEF

Summary

- Determining optimal vessel fleets for maintenance operations at offshore wind farms is challenging
- We have developed a vessel fleet optimization model for decision support
- An efficient metaheuristic solution procedure has been implemented
  - Greedy randomized adaptive search procedure
  - Uncertainty in weather conditions and corrective maintenance tasks considered by a simulation procedure
  - Reports optimal vessel fleet compared with exact solution method
- Decision support tool can aid many actors in the offshore wind industry

SINTEF

References

- Cradden, L.; Gebruers, C.; Halvorsen-Weare, E.E.; Irawan, C.; Nonås, L.M.; Norstad, I.; Pappas, T.; Schäffer, L.E. (2016), "Mathematical optimisation models and methods for transport systems". LEANWIND Deliverable 5.6.
- Sperstad, I.B.; Stålhane, M.; Dinwoodie, I.; Endrerud, O.-E.V.; Martin, R.; Warner E. (2016), "Testing the Robustness of Optimal Vessel Fleet Selection for Operation and Maintenance of Offshore Wind Farms". (Unpublished.)
- Stålhane, M.; Halvorsen-Weare, E.E., Nonås, L.M. (2014), "FAROFF Optimization model technical report", MARINTEK Report MT2014 F-097.
- Stålhane, M.; Halvorsen-Weare, E.E.; Nonås, L.M. (2016), "A decision support system for vessel fleet analysis for maintenance operations at offshore wind farms", Working paper. (Unpublished.)

SINTEF

Technology for a better society