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Optimizing Jack-Up Vessel Chartering Strategies for Offshore Wind Farms

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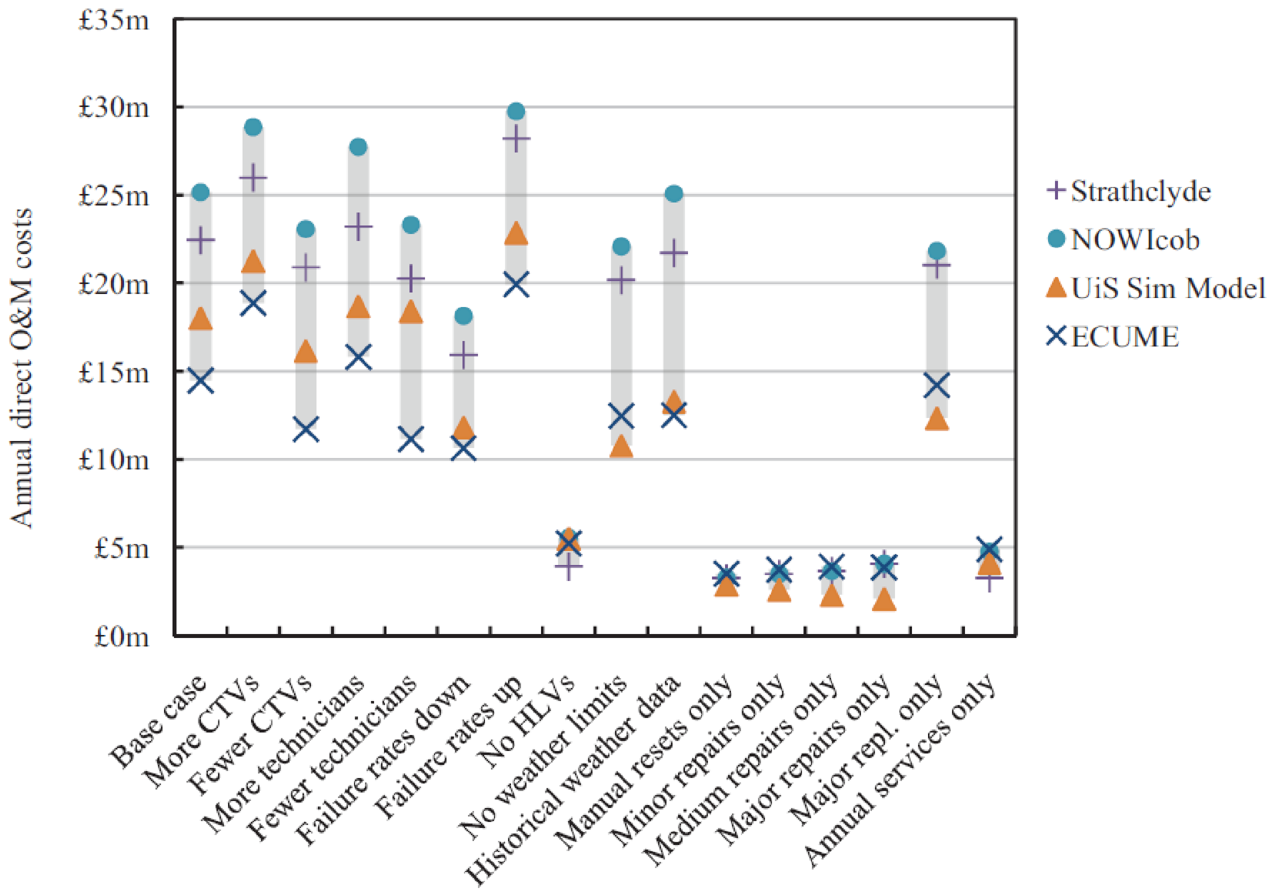
Outline

- Motivation
- Problem description
- Mathematical model
- Preliminary results
- Further research

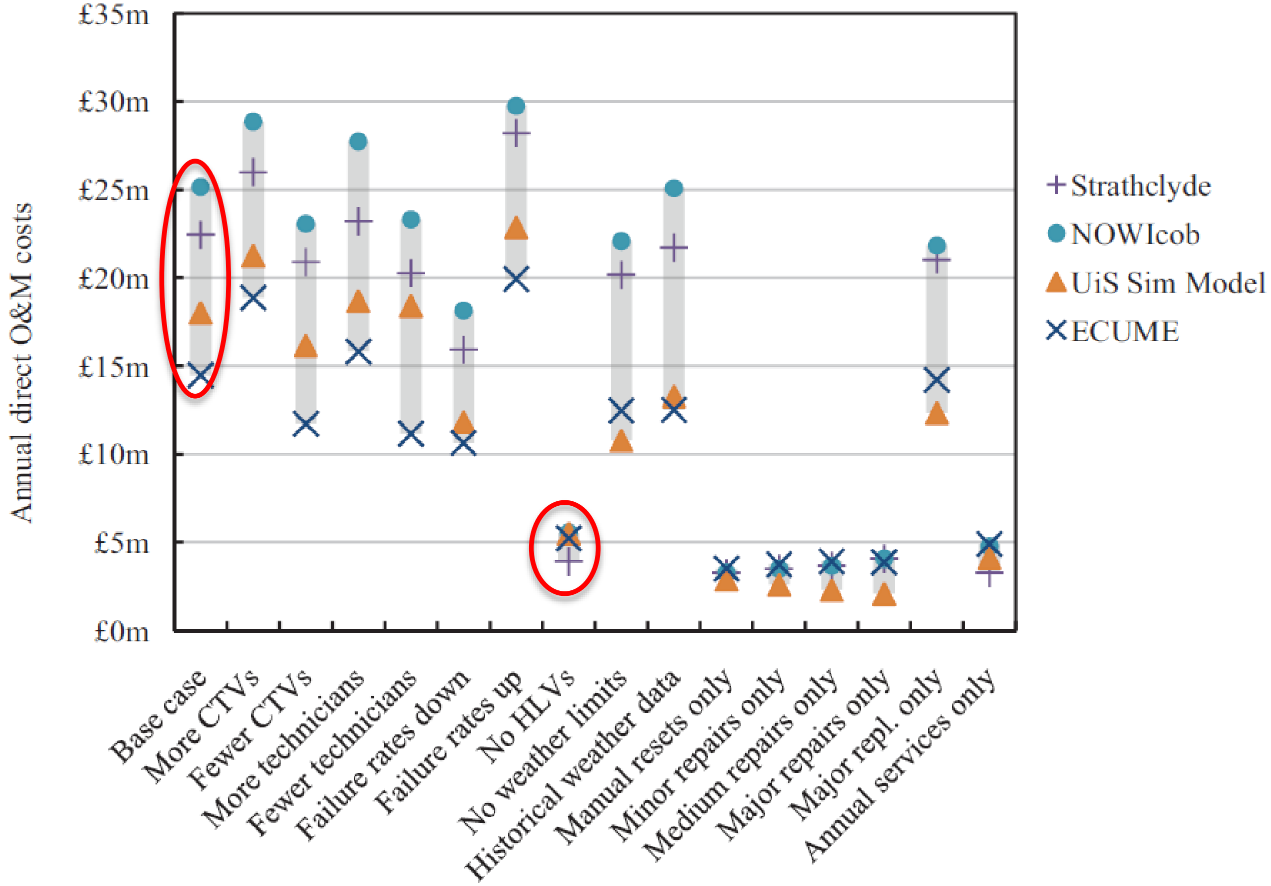
Jack-up vessel

Motivation



*from Dinwoodie et al (2015)

Motivation



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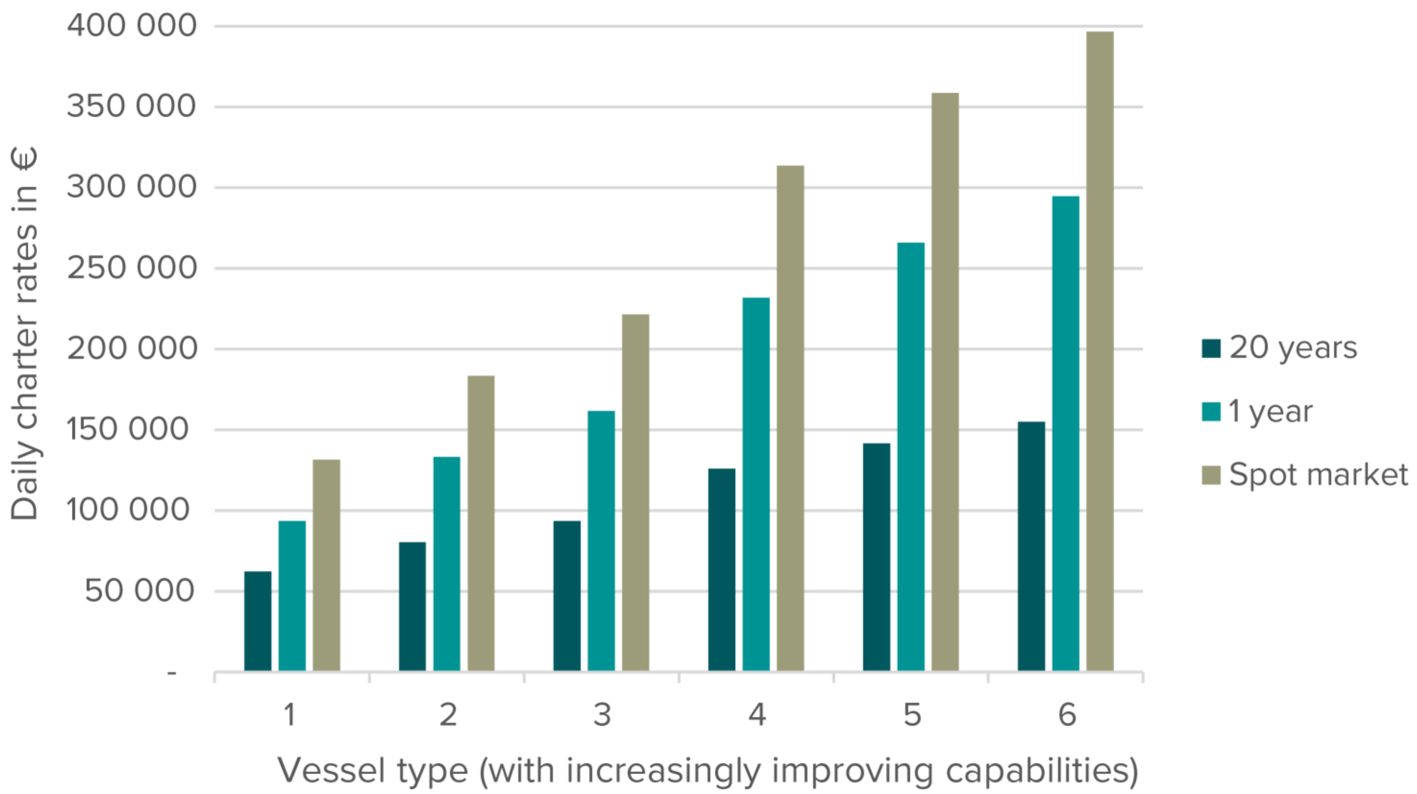
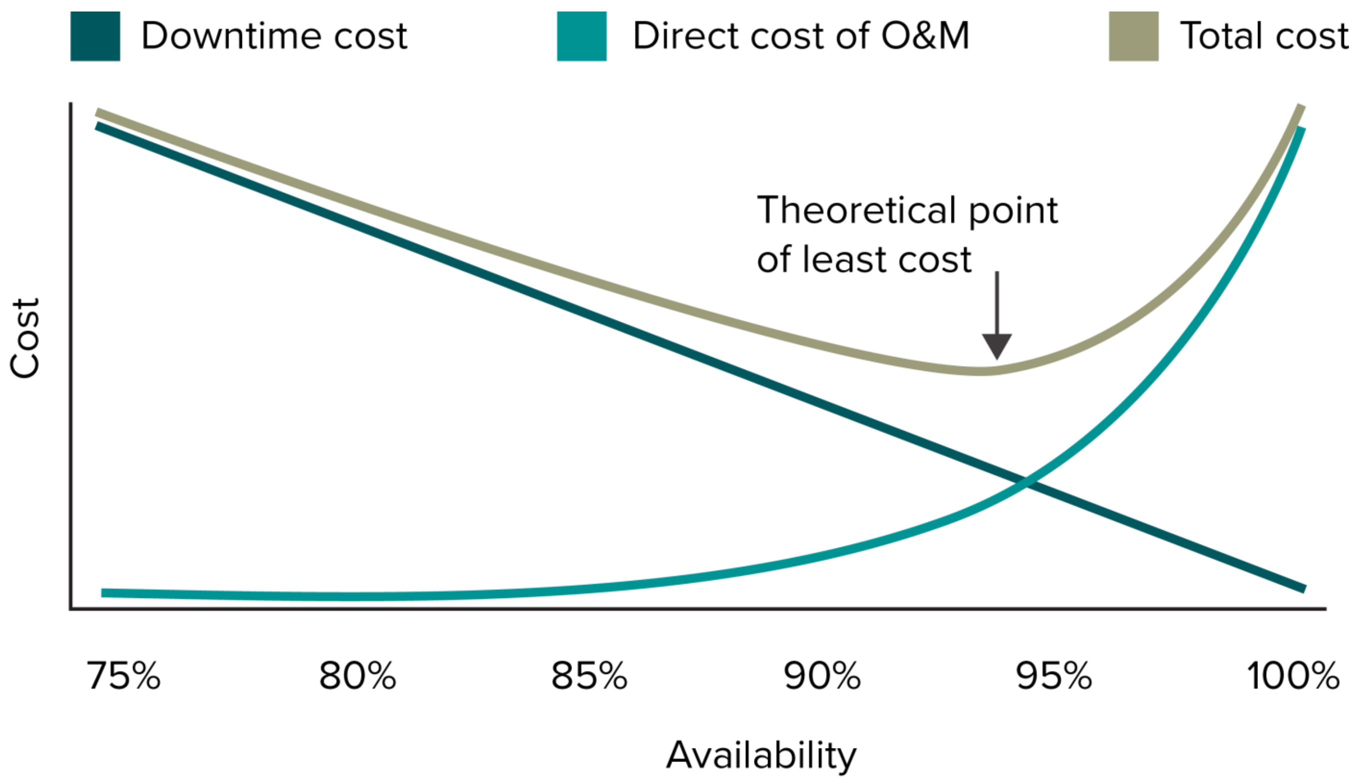
Jack-up vessel charter rates



*Based on data from Dalgic et al (2013)


Downtime cost
Direct cost of O&M
Total cost
Theoretical point
of least cost
Cost
75%
80%
85%
90%
95%
100%
Availability

Current Jack-Up Charter Practices

- Options:
  - Annual charter
  - Fix-on-fail
  - Batch-repair
- Difficult to determine best option
- Obstacles:
  - Inflexibility
  - Expensive
  - Determining optimal batch
  - Uncertainty

Optimal jack-up strategy depends on:

- Size of the wind farm
- Weather conditions at the wind farm site
- Failure rate of the components
- Charter rate for jack-up vessels
- Capabilities of the jack-up vessels

- Goal: To determine when, and for how long, to charter in a jack-up vessel in order to minimize expected total O&M cost.

Mathematical model

- Uncertain parameters:
  - When failures that require jack-up vessels occur
  - The weather conditions at the wind farm site each day of the planning horizon
- Two-stage stochastic optimization model
  - First stage: Decide when, and for how long, to charter a jack-up vessel
  - Second stage: Given first stage decision, how to deploy the jack-up vessel in order to minimize the downtime cost

First stage model

$$\min \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^P_{vt} y_{vt} + \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^M_v v_{vt} + E_\xi[Q(y,\xi)]$$

$$\begin{aligned}
& y_{vt} - y_{v(t-1)} \le v_{vt}, && v\in\mathcal{V}, t\in\mathcal{T}\setminus\{1\},\\
& y_{v1} - y_{|\mathcal{T}|} \le v_{vt}, && v\in\mathcal{V},\\
& \sum_{\tau=t}^{t+\underline{T}^L-1} y_\tau \ge \underline{T}^L v_t, && v\in\mathcal{V}, t\in\mathcal{T}: t\le|\mathcal{T}|-\underline{T}^L+1,\\
& \sum_{\tau=t}^{|\mathcal{T}|} y_\tau + \sum_{\tau=1}^{t+\underline{T}^L-|\mathcal{T}|-1} y_\tau \ge \underline{T}^L v_t, && v\in\mathcal{V}, t\in\mathcal{T}: t\ge|\mathcal{T}|-\underline{T}^L,\\
& y_{vt}\in\{0,1\}, && v\in\mathcal{V}, t\in\mathcal{T},\\
& v_{vt}\in\{0,1\}, && v\in\mathcal{V}, t\in\mathcal{T}.
\end{aligned}$$

First stage model

Daily charter rate

$$\min \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^P_{vt} y_{vt} + \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^M_v v_{vt} + E_\xi[Q(y,\xi)]$$

$$y_{vt} - y_{v(t-1)} \leq v_{vt}, \qquad v\in\mathcal{V}, t\in\mathcal{T}\setminus\{1\},$$

$$y_{v1} - y_{|\mathcal{T}|} \leq v_{vt}, \qquad v\in\mathcal{V},$$

$$\sum_{\tau=t}^{t+\underline{T}^L-1} y_\tau \geq \underline{T}^L v_t, \qquad v\in\mathcal{V}, t\in\mathcal{T}: t\leq|\mathcal{T}|-\underline{T}^L+1,$$

$$\sum_{\tau=t}^{|\mathcal{T}|} y_\tau + \sum_{\tau=1}^{t+\underline{T}^L-|\mathcal{T}|-1} y_\tau \geq \underline{T}^L v_t, \qquad v\in\mathcal{V}, t\in\mathcal{T}: t\geq|\mathcal{T}|-\underline{T}^L,$$

$$y_{vt}\in\{0,1\}, \qquad v\in\mathcal{V}, t\in\mathcal{T},$$

$$v_{vt}\in\{0,1\}, \qquad v\in\mathcal{V}, t\in\mathcal{T}.$$

First stage model

Mobilisation rate

$$\min \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^P_{vt} y_{vt} + \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^M_v v_{vt} + E_\xi[Q(y,\xi)]$$

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\end{aligned}$$

First stage model

Expected total downtime cost

$$\min \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^P_{vt} y_{vt} + \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^M_v v_{vt} + E_\xi[Q(y,\xi)]$$

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\end{aligned}$$

First stage model

$$\min \sum_{v \in \mathcal{V}} \sum_{t \in \mathcal{T}} C^P_{vt} y_{vt} + \sum_{v \in \mathcal{V}} \sum_{t \in \mathcal{T}} C^M_v v_{vt} + E_\xi[Q(y,\xi)]$$

Must mobilize vessel to have it available

$$v \in \mathcal{V}, t \in \mathcal{T} \setminus \{1\},$$

$$y_{v1} - y_{|\mathcal{T}|} \leq v_{vt}, \qquad v \in \mathcal{V},$$

$$\sum_{\tau=t}^{t+\underline{T}^L-1} y_\tau \geq \underline{T}^L v_t, \qquad v \in \mathcal{V}, t \in \mathcal{T} : t \leq |\mathcal{T}| - \underline{T}^L + 1,$$

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First stage model

$$\min \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^P_{vt} y_{vt} + \sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} C^M_{v} v_{vt} + E_\xi[Q(y,\xi)]$$

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& y_{vt}\in\{0,1\}, && v\in\mathcal{V}, t\in\mathcal{T},\\
& v_{vt}\in\{0,1\}, && v\in\mathcal{V}, t\in\mathcal{T}.
\end{aligned}$$

Must keep vessel for a minimum number of days, if mobilised

Second stage model

$$Q(y^*, \xi) = \min \sum_{v \in \mathcal{V}} \sum_{c \in \mathcal{C}} \sum_{f \in \mathcal{F}_c(\xi)} \sum_{t_2 \in \mathcal{T}} C^D_{vct(f)t_2}(\xi) x_{vft_2} + \sum_{c \in \mathcal{C}} \sum_{f \in \mathcal{F}_c(\xi)} C^P z_f,$$

$$\sum_{c \in \mathcal{C}} \sum_{f \in \mathcal{F}_c(\xi)} \sum_{t \in \mathcal{T}} A_{vct\tau}(\xi) x_{vft} \leq y^*_{v\tau}, \qquad v \in \mathcal{V}, \tau \in \mathcal{T},$$

$$\sum_{v \in \mathcal{V}} \sum_{t \in \mathcal{T}} x_{vft} + z_f = 1, \qquad c \in \mathcal{C}, f \in \mathcal{F}_c,$$

$$x_{vft} \in \{0, 1\}, \qquad v \in \mathcal{V}, f \in \mathcal{F}, t \in \mathcal{T},,$$

$$z_f \in \{0, 1\}, \qquad f \in \mathcal{F},.$$

Second stage model

Downtime cost of fixing a failure on a given day

$$Q(y^*, \xi) = \min \sum_{v \in \mathcal{V}} \sum_{c \in \mathcal{C}} \sum_{f \in \mathcal{F}_c(\xi)} \sum_{t_2 \in \mathcal{T}} C^D_{vct(f)t_2}(\xi) x_{vft_2} + \sum_{c \in \mathcal{C}} \sum_{f \in \mathcal{F}_c(\xi)} C^P z_f,$$

$$\sum_{c \in \mathcal{C}} \sum_{f \in \mathcal{F}_c(\xi)} \sum_{t \in \mathcal{T}} A_{vct\tau}(\xi) x_{vft} \leq y^*_{v\tau}, \qquad v \in \mathcal{V}, \tau \in \mathcal{T},$$

$$\sum_{v \in \mathcal{V}} \sum_{t \in \mathcal{T}} x_{vft} + z_f = 1, \qquad c \in \mathcal{C}, f \in \mathcal{F}_c,$$

$$x_{vft} \in \{0, 1\}, \qquad v \in \mathcal{V}, f \in \mathcal{F}, t \in \mathcal{T},,$$

$$z_f \in \{0, 1\}, \qquad f \in \mathcal{F},.$$

Second stage model

Penalty cost applied if a failure is not fixed

$$Q(y^*,\xi) = \min \sum_{v\in\mathcal{V}} \sum_{c\in\mathcal{C}} \sum_{f\in\mathcal{F}_c(\xi)} \sum_{t_2\in\mathcal{T}} C^D_{vct(f)t_2}(\xi) x_{vft_2} + \sum_{c\in\mathcal{C}} \sum_{f\in\mathcal{F}_c(\xi)} C^P z_f,$$

$$\sum_{c\in\mathcal{C}} \sum_{f\in\mathcal{F}_c(\xi)} \sum_{t\in\mathcal{T}} A_{vct\tau}(\xi) x_{vft} \le y^*_{v\tau}, \qquad v\in\mathcal{V}, \tau\in\mathcal{T},$$

$$\sum_{v\in\mathcal{V}} \sum_{t\in\mathcal{T}} x_{vft} + z_f = 1, \qquad c\in\mathcal{C}, f\in\mathcal{F}_c,$$

$$x_{vft}\in\{0,1\}, \qquad v\in\mathcal{V}, f\in\mathcal{F}, t\in\mathcal{T},,$$

$$z_f\in\{0,1\}, \qquad f\in\mathcal{F},.$$

Second stage model

$$Q(y^*,\xi) = \min \sum_{v\in\mathcal{V}}\sum_{c\in\mathcal{C}}\sum_{f\in\mathcal{F}_c(\xi)}\sum_{t_2\in\mathcal{T}} C^{D}_{vct(f)t_2}(\xi)x_{vft_2} + \sum_{c\in\mathcal{C}}\sum_{f\in\mathcal{F}_c(\xi)} C^{P} z_f,$$

Faliures can only be fixed in time periods the vessel is chartered. Repair time is weather dependent

$$\sum_{c\in\mathcal{C}}\sum_{f\in\mathcal{F}_c(\xi)}\sum_{t\in\mathcal{T}} A_{vct\tau}(\xi)x_{vft} \le y_{v\tau}, \qquad v\in\mathcal{V}, \tau\in\mathcal{T},$$

$$\sum_{v\in\mathcal{V}}\sum_{t\in\mathcal{T}} x_{vft} + z_f = 1, \qquad c\in\mathcal{C}, f\in\mathcal{F}_c,$$

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Second stage model

$$Q(y^*, \xi) = \min \sum_{v \in \mathcal{V}} \sum_{c \in \mathcal{C}} \sum_{f \in \mathcal{F}_c(\xi)} \sum_{t_2 \in \mathcal{T}} C^D_{vct(f)t_2}(\xi) x_{vft_2} + \sum_{c \in \mathcal{C}} \sum_{f \in \mathcal{F}_c(\xi)} C^P z_f,$$

$$v \in \mathcal{V}, \tau \in \mathcal{T},$$

All failures must be fixed, otherwise a penalty is added

$$\sum_{v \in \mathcal{V}} \sum_{t \in \mathcal{T}} x_{vft} + z_f = 1, \qquad c \in \mathcal{C}, f \in \mathcal{F}_c,$$

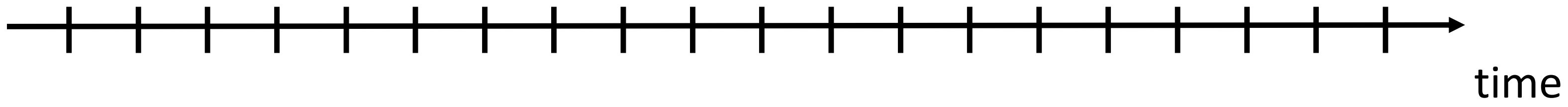
$$x_{vft} \in \{0, 1\}, \qquad v \in \mathcal{V}, f \in \mathcal{F}, t \in \mathcal{T},,$$

$$z_f \in \{0, 1\}, \qquad f \in \mathcal{F},.$$

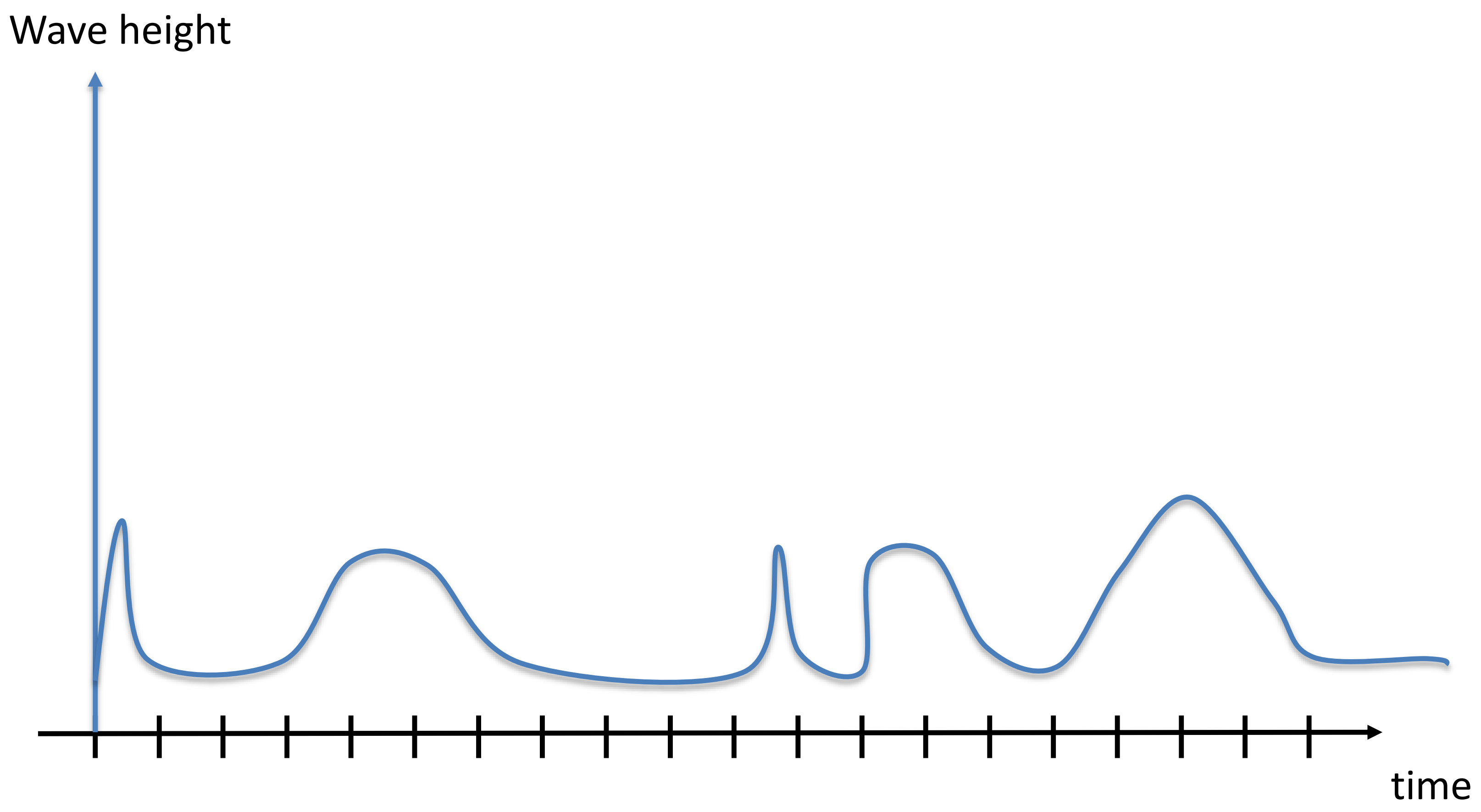
Solution method

- The two-stage stochastic programming model is solved using scenario generation and then solving the deterministic equivalent
- Each scenario represents one realisation of one year

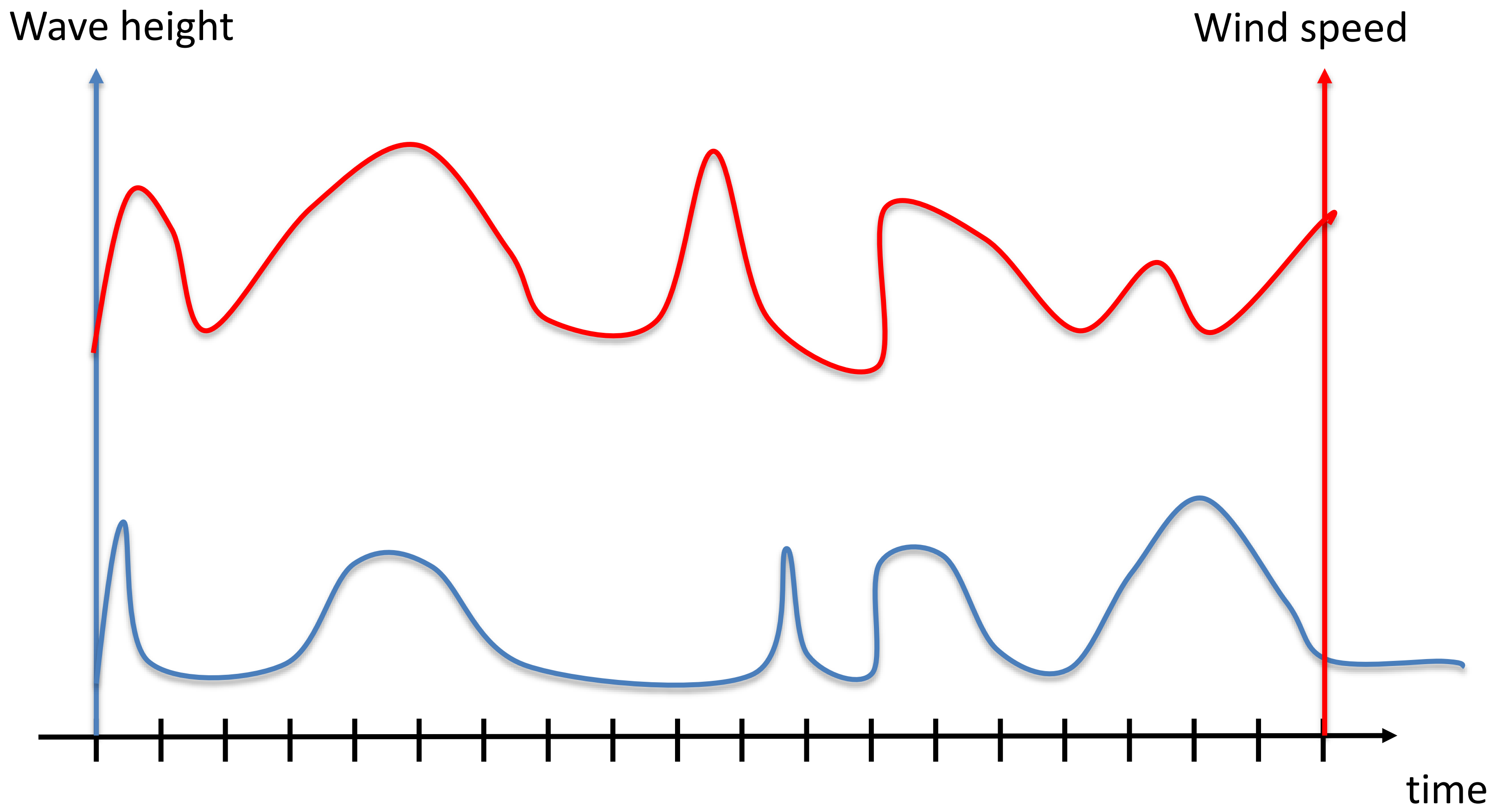
Scenario



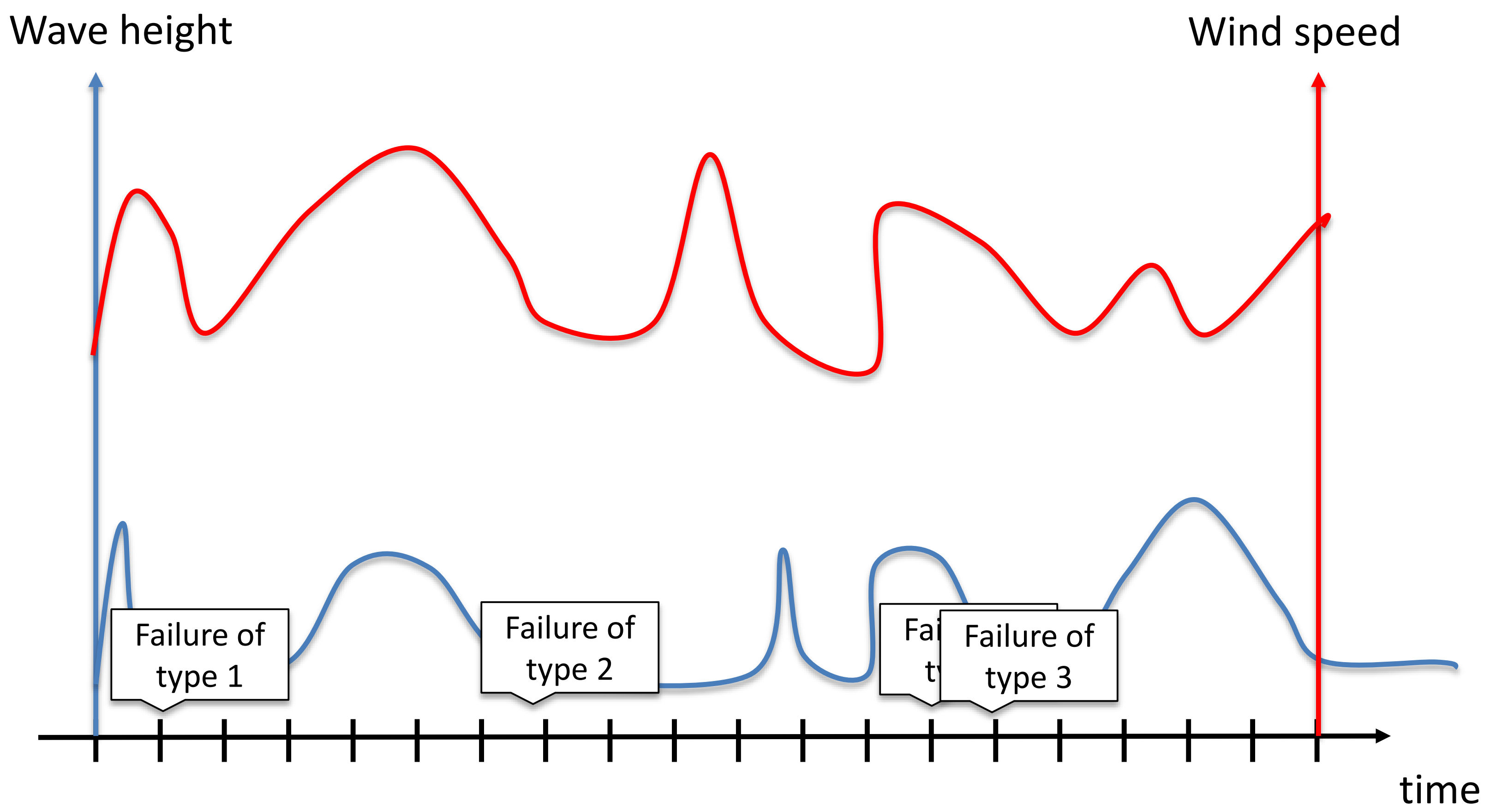
Scenario



Scenario

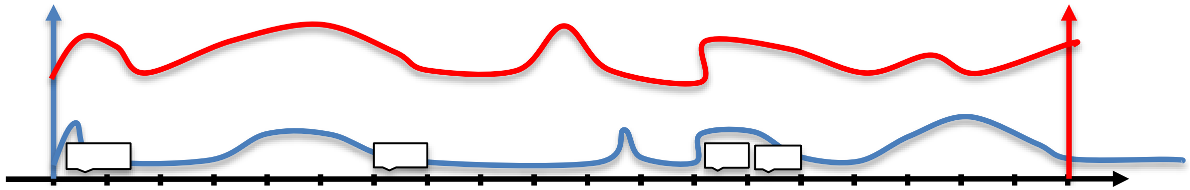


Scenario

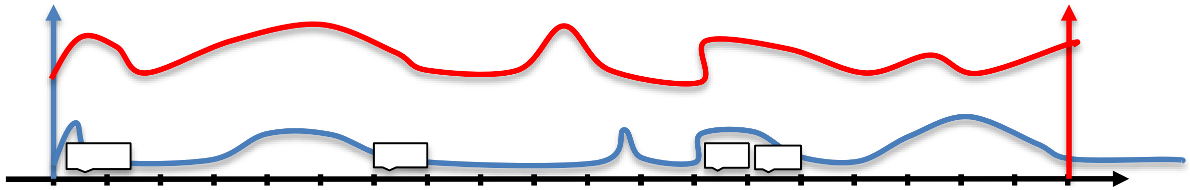

Wave height
Wind speed
Failure of type 1
Failure of type 2
Failure of type 3
time

Scenarios

Scenario 1



Scenario 2



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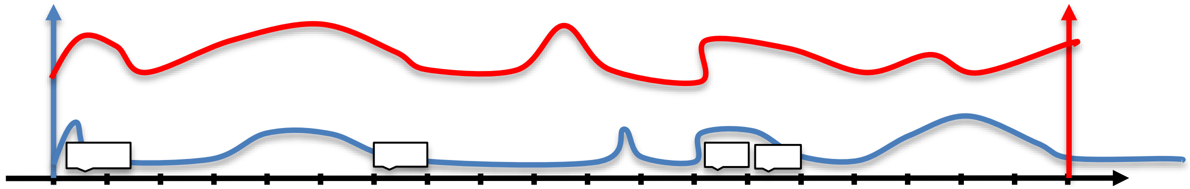
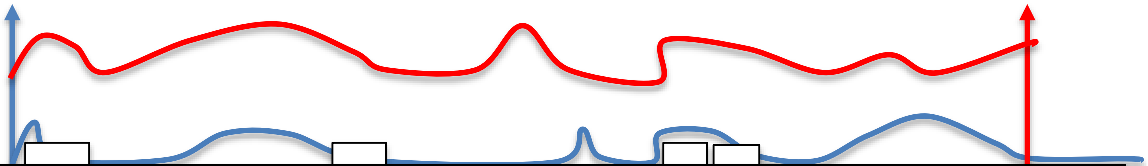
Scenario n



Scenarios

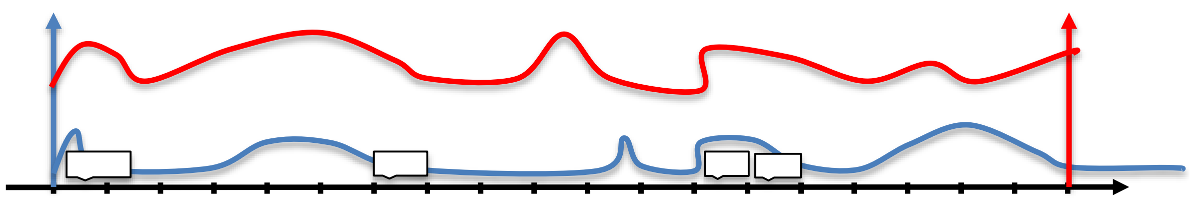
Scenario 1



Scenario 2

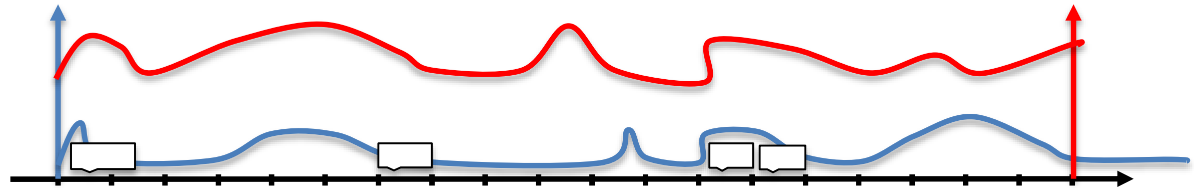
All scenarios represent different possible realisations of the weather and failure parameters based on sampling

Scenario n

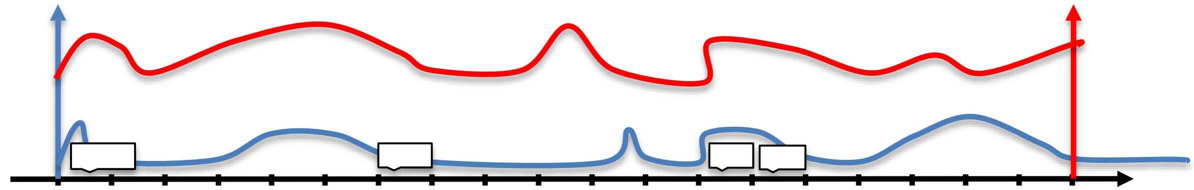


Scenarios

Scenario 1

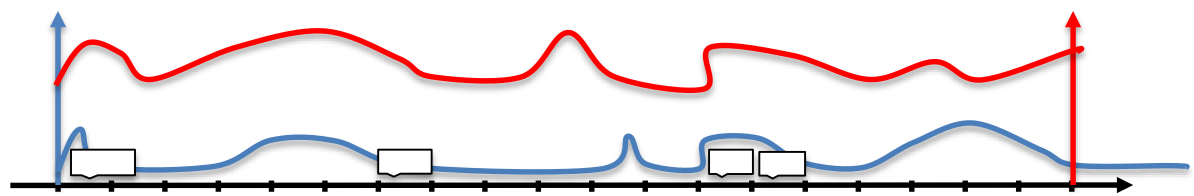


Scenario 2



⋮

Scenario n

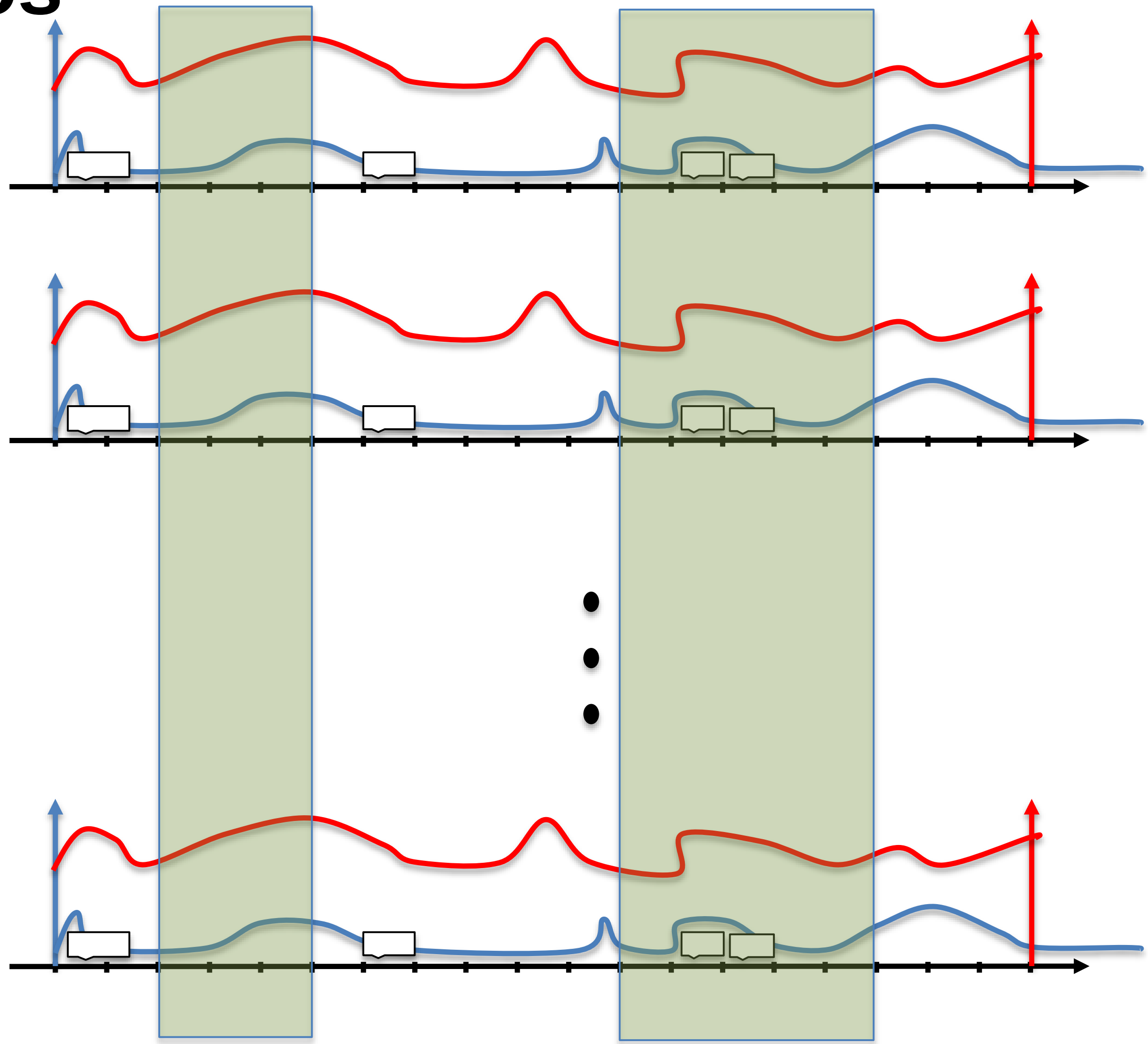


First stage decisions – must be the same in all scenarios

Scenario 1

Scenario 2

Scenario n



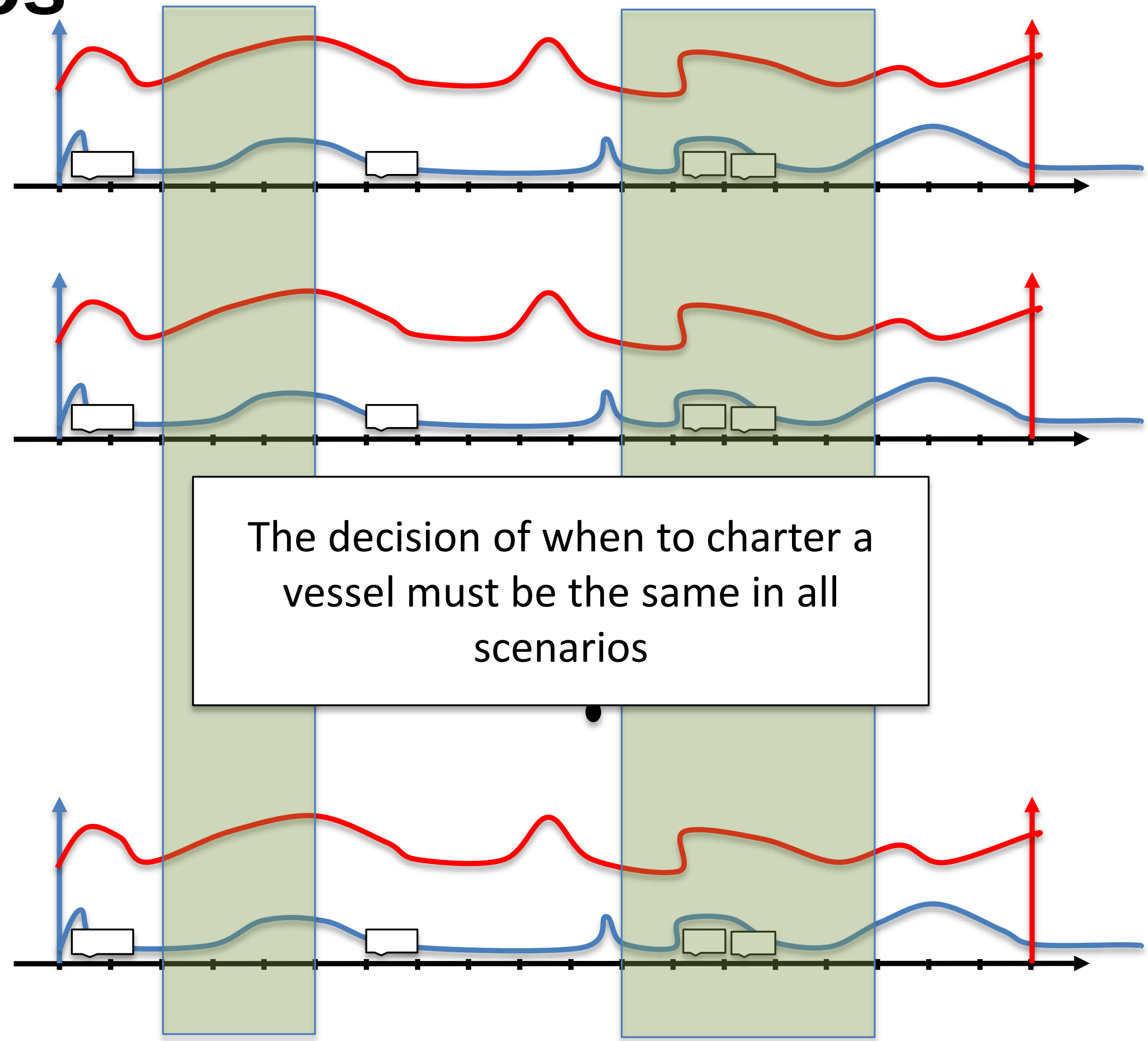
First stage decisions – must be the same in all scenarios

Scenario 1

Scenario 2

•
•
•

Scenario n

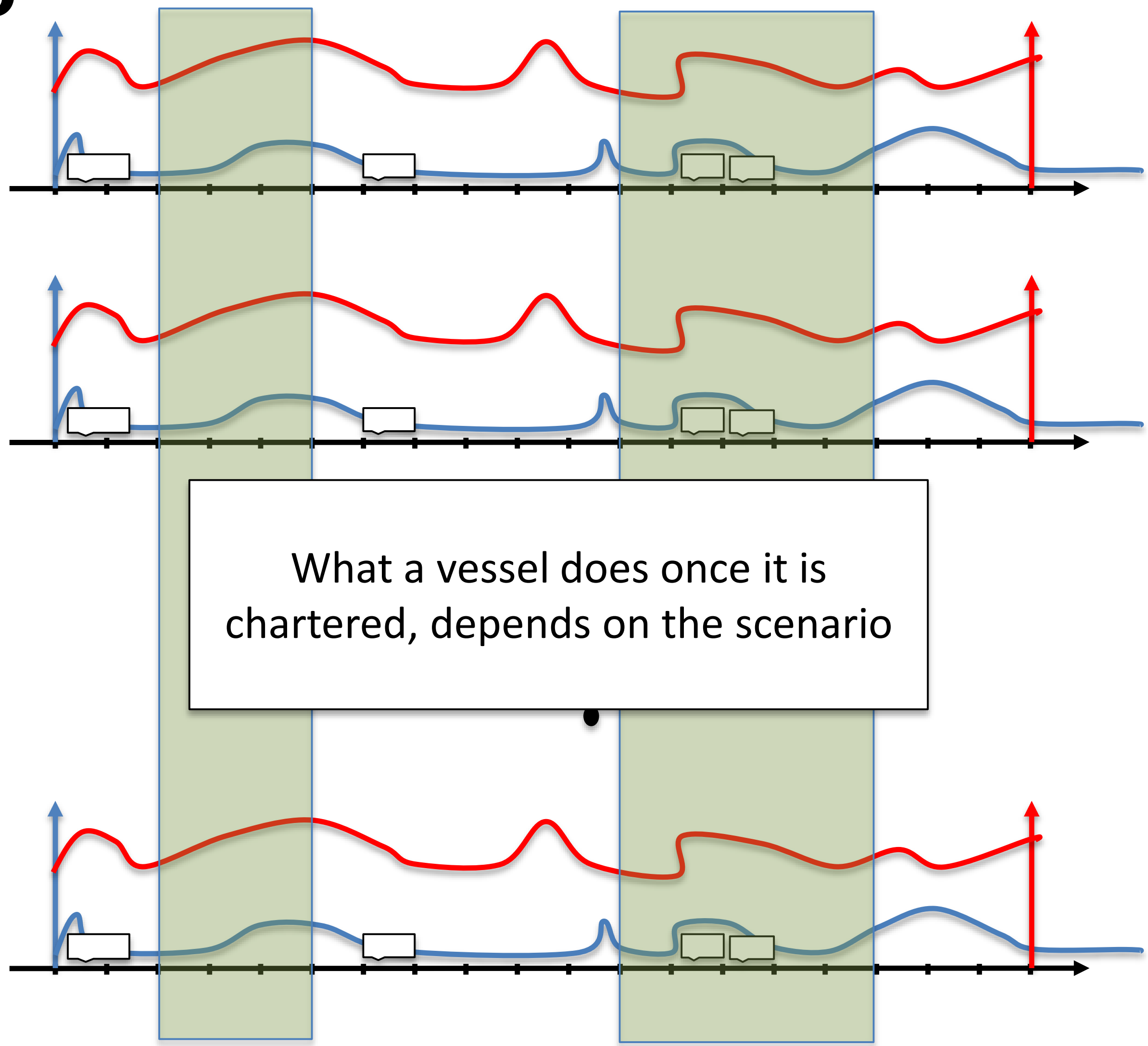


Second stage decisions – different for each scenario

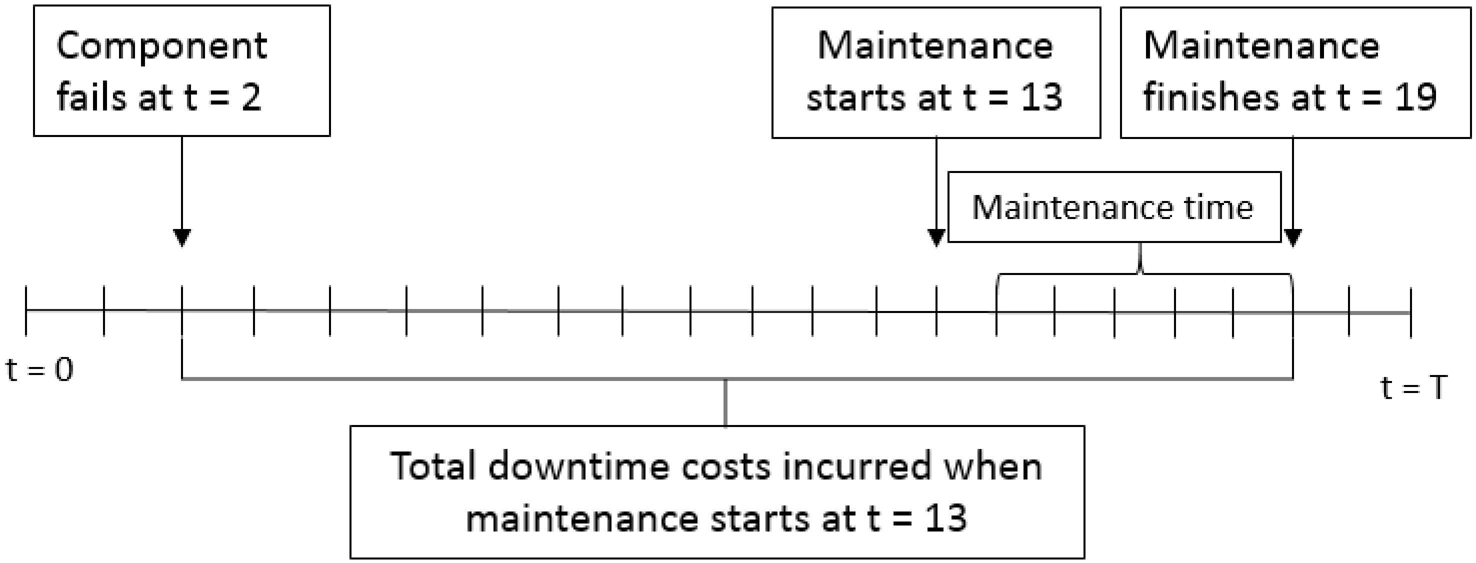
Scenario 1

Scenario 2

Scenario n



Second stage decision – when to fix a given failure



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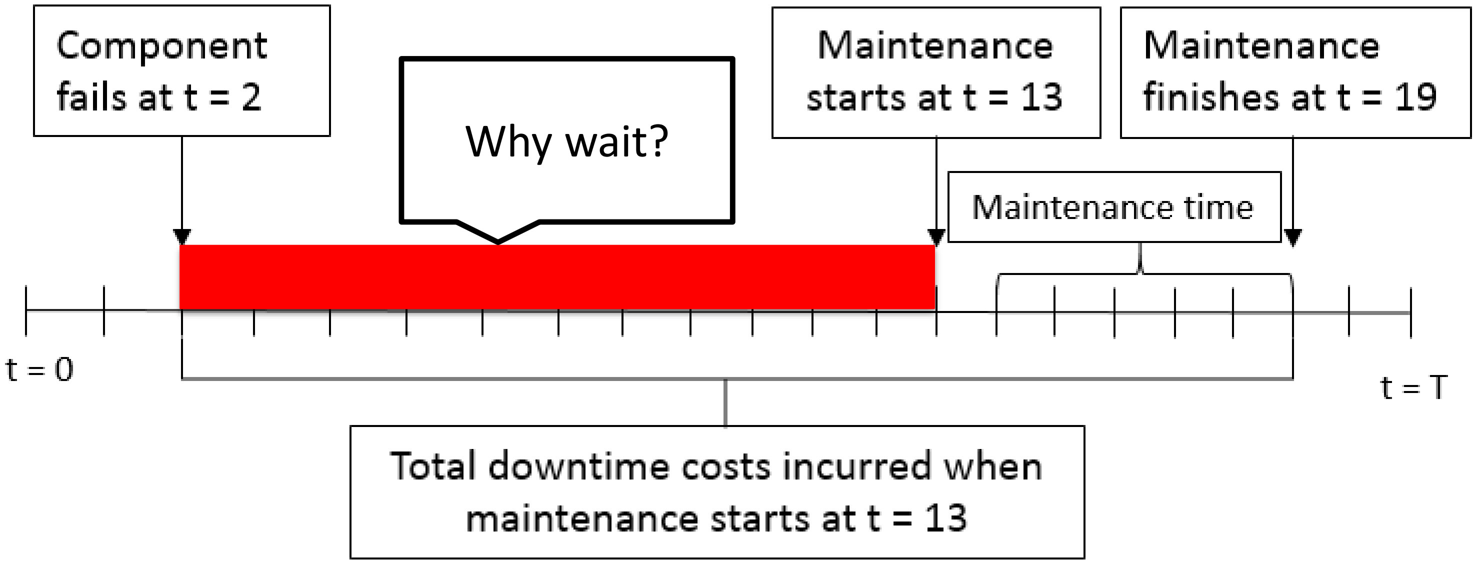
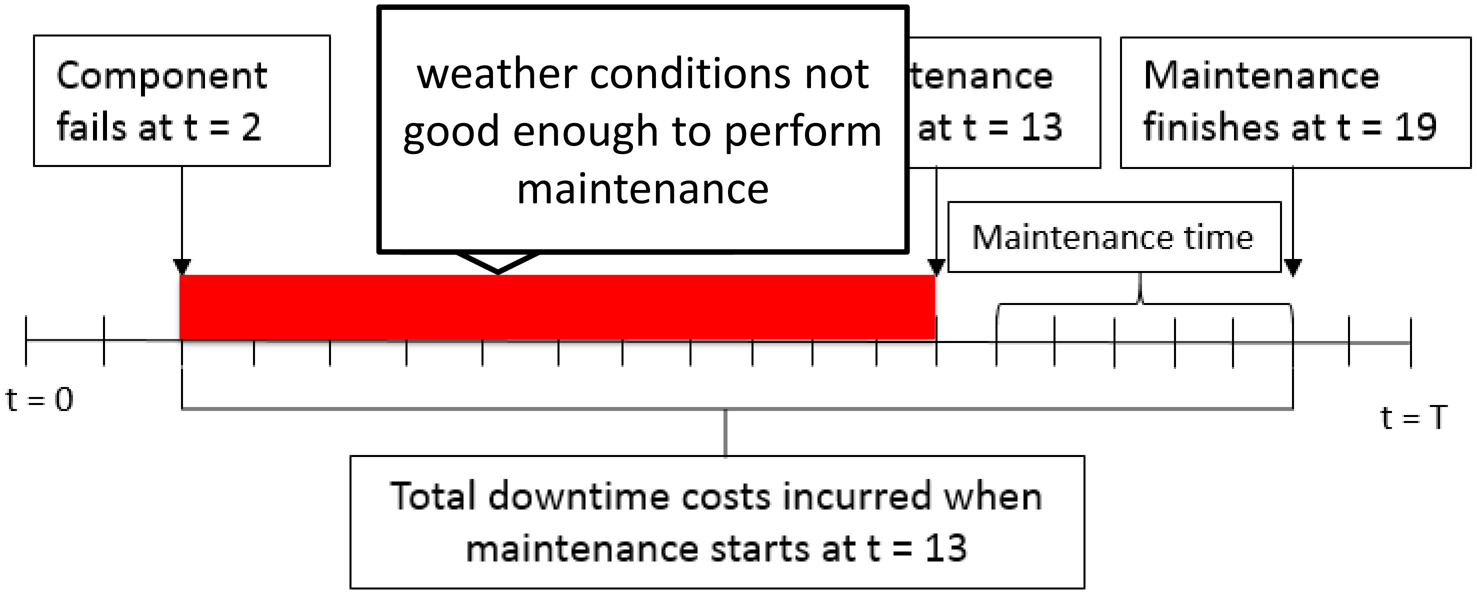
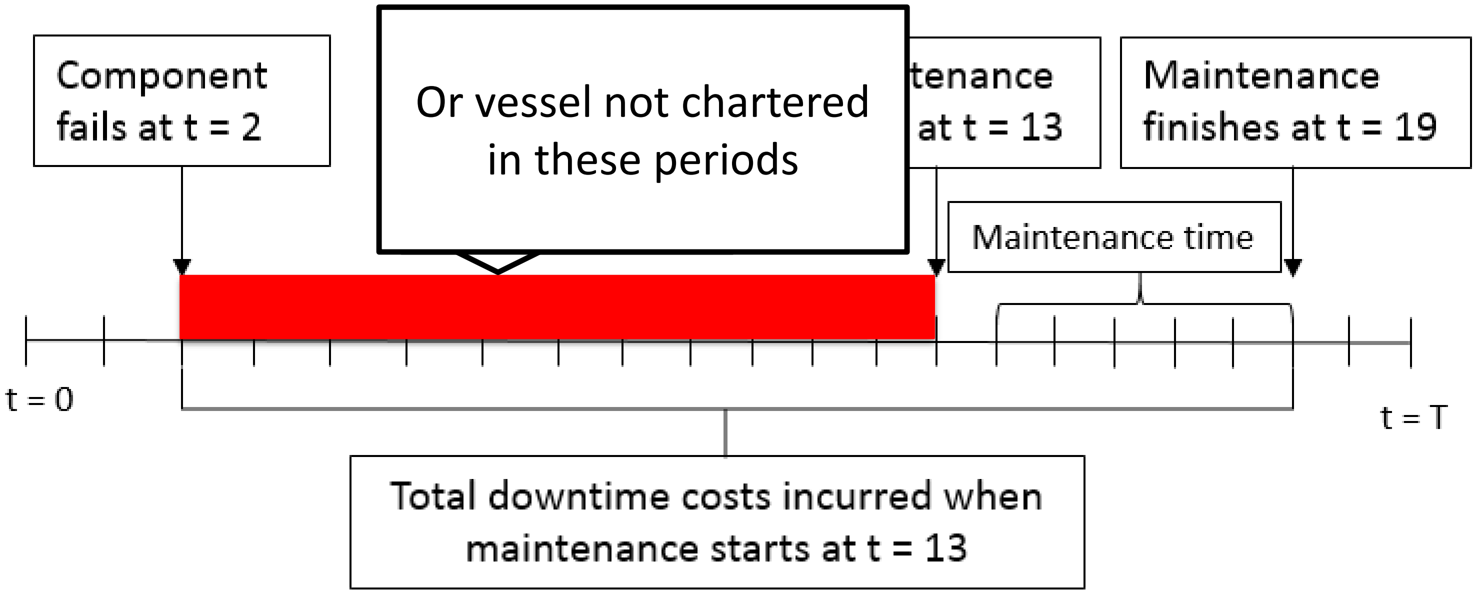


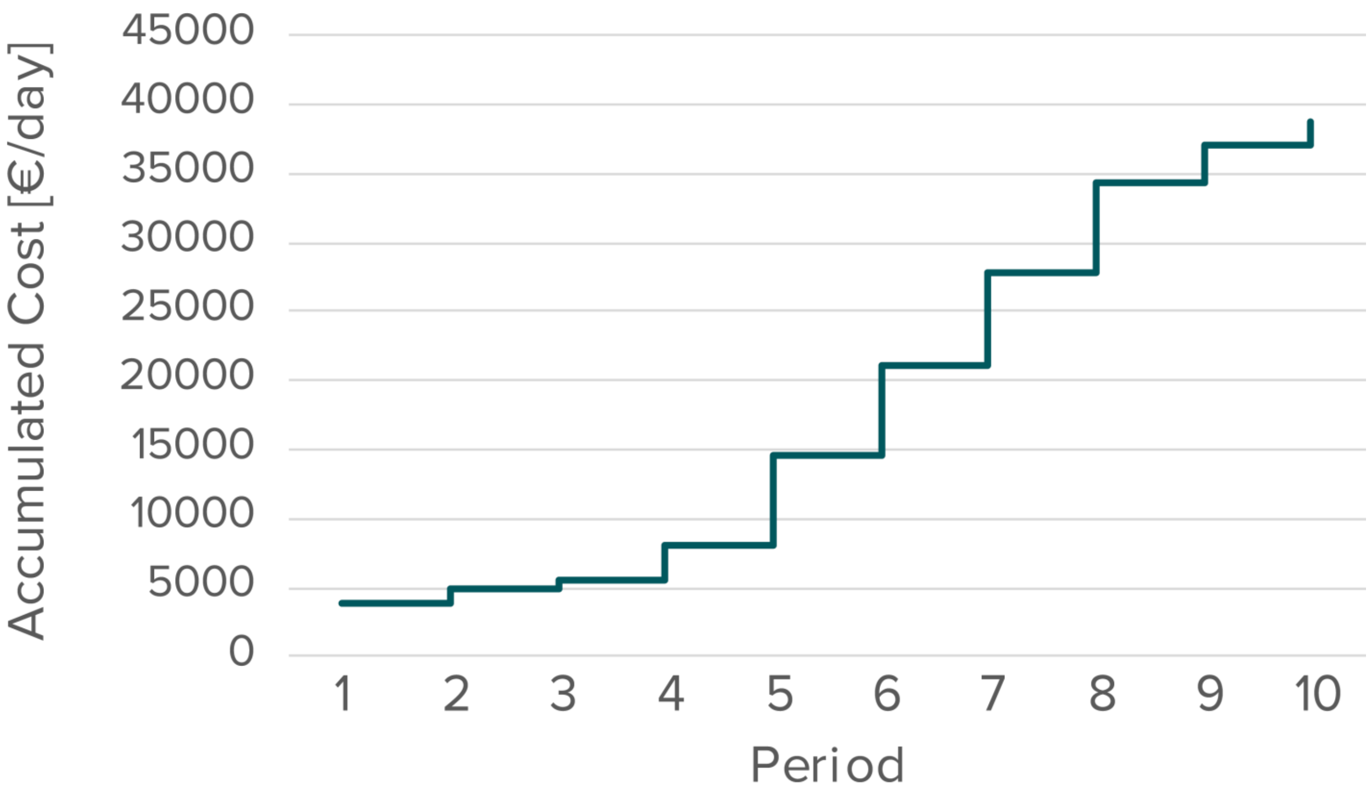
Second stage decision – when to fix a given failure



Second stage decision – when to fix a given failure



Downtime costs – depends on wind speed



Preliminary Results

- The model is able to solve one-year problems with 100 scenarios
- Weather conditions at site and vessel capabilities greatly affect results
- Anything from 50 to 200 days of charter for a 80-100 turbine wind farm

Future reasearch

- Ensure realistic data
  - Huge differences in values used in different research
- Verify model results in a cost of energy simulation model
- Compare strategy with batch-repair strategy
- Add possibility of sub-leasing

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