

Initial models for optimisation

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Initial model for installation

$$\max_{\substack{O_p, N_{rp} \in \mathbb{Z}^* \\ s_{ait} \in \{0,1\}}} \sum_{p \in P} [DIS^p(O_p \cdot v_p - \sum_{r \in R} N_{rp} \cdot C_{rp})] \quad (1)$$

subject to:

$$s_{ait} \leq s_{ai(t+1)} \quad \forall a \in A, \forall i \in I, \forall t \in T \quad (2)$$

$$s_{ai\sigma_{itN}} \geq 1 \quad \forall a \in A, \forall i \in I \quad (3)$$

$$s_{ajt} \leq s_{ai\sigma_{it}} \quad \forall a \in A, \forall (i,j) \in IP, \forall t \in T \quad (4)$$

$$N_{rp} \geq \sum_{a \in A} \sum_{i \in I} (\rho_{ir} \cdot (s_{ait} - s_{ai\sigma_{it}})) \quad \forall r \in R, \forall p \in P, \forall t \in T_p \quad (5)$$

$$O_p = \sum_{a \in A} s_{aiN\sigma_{iNt_p}} \quad \forall p \in P \quad (6)$$

$$N_{rp} \leq m_{rp} \quad \forall r \in R, \forall p \in P \quad (7)$$

Installation Model Explanation

- (1) Objective function, sums up profits from energy made, subtracts money used on resources (vessels), and multiplies it all with a discount factor
- (2) Makes every task that is started stay started
- (3) Forces every task to be started and finished by the final timestep
- (4) For every precedence relation (i, j) , ensures that i is finished before j is started
- (5) Counts up the resources needed in a time period by adding the resources needed by all tasks started, and subtracting the resources needed by all tasks finished
- (6) Counts the number of turbines which finished installing by the end of a period
- (7) Sets a limit on the amount of vessels that can be charatered in a given period

Notation overview

Sets:

- P : All time periods (large scale)
- T : All time intervals (small scale)
 $[t_0, \dots, t_N]$
- $T_p \in T$: All time intervals (small scale)
in period p
- R : All resources
- I : All tasks per asset $[1, \dots, i_N]$
- IP : All precedence pairs (i, j)
- A : All assets

Decision variables:

- O_p : Number of online turbines after
period p
- N_{rp} : Number of resources r used in
period p
- s_{ait} : Binary variable, 1 if task $i \in I$ for
asset a has started at or before time t

Parameters:

- DIS : The discount factor per period
- v_p : The value of energy a single turbine
produces in period p
- C_{rp} : The cost of chartering resource r
in period p
- σ_{it} : Indicates the timestep at which
task i should have been started for it to
be finished by timestep t , taking into
account the duration and the weather
conditions
- ρ_{ir} : The amount of resource r used by
task i
- t_p : The final time interval (from T)
before period p
- m_{rp} : The maximum amount of
resources r that can be chartered in
period p

Initial model for maintenance

$$\max_{\substack{O_t, N_{rp} \in \mathbb{Z}^* \\ s_{ait}, b_{at} \in \{0,1\}}} \sum_{p \in P} [DIS^p(\sum_{t \in T_p} (O_t \cdot v_t) - \sum_{r \in R} (N_{rp} \cdot C_{rp}))] \quad (8)$$

subject to:

$$s_{ait} \leq s_{ai(t+1)} \quad \forall a \in A, \forall i \in M, \forall t \in T \quad (9)$$

$$s_{ai\sigma_{itN}} \geq 1 \quad \forall a \in A, \forall i \in M^M \quad (10)$$

$$N_{rp} \geq \sum_{a \in A} \sum_{i \in M} (\rho_{ir} \cdot (s_{ait} - s_{ai\sigma_{it}})) \quad \forall r \in R, \forall p \in P, \forall t \in T_p \quad (11)$$

$$b_{at} > \sum_{i \in M} [s_{ai\sigma_{i(t-\lambda_a)}} - s_{ai\sigma_{it}}] \quad \forall a \in A, \forall t \in T \quad (12)$$

$$O_t = |A| - \sum_{a \in A} b_{at} \quad \forall t \in T \quad (13)$$

$$N_{rp} \leq m_{rp} \quad \forall r \in R, \forall p \in P \quad (14)$$

Maintenance Model Explanation

- (8) Objective function, sums up profits from energy made, subtracts money used on resources (vessels), and multiplies it all with a discount factor
- (9) Makes every task that is finished stay finished
- (10) Forces every mandatory maintenance task to be done at some point
- (11) Counts up the resources needed in a time period by adding the resources needed by all tasks started, and subtracting the resources needed by all tasks finished
- (12) If no maintenance tasks have finished in the past λ_a timesteps this asset is broken
- (13) The number of active (online) turbines is equal to everything that isn't broken
- (14) Sets a limit on the amount of vessels that can be charatered in a given period

Notation overview

Sets:

- P : All time periods (large scale)
- T : All time intervals (small scale)
 $[t_0, \dots, t_N]$
- $T_p \in T$: All time intervals (small scale)
in period p
- R : All resources
- A : All assets
- $M = M^M \cup M^O$: All (mandatory and optional) maintenance tasks

Decision variables:

- O_t : Number of active turbines at timestep t
- N_{rp} : Number of resources r used in period p
- s_{ait} : Binary variable, 1 if maintenance task i for asset a has started at or before time t
- b_{at} : Binary variable, 1 if asset a is broken at timestep t

Parameters:

- DIS : The discount factor per time period
- v_t : The value of energy a single turbine produces at timestep t
- C_{rp} : The cost of chartering resource r in period p
- λ_a : The number of timesteps after the last maintenance before asset a fails
- σ_{it} : Indicates the timestep at which task i should have been started for it to be finished by timestep t , taking into account the duration and the weather conditions
- ρ_{ir} : The amount of resource r used per task for maintenance task i
- m_{rp} : The maximum amount of resources r that can be chartered in period p

Initial 2-mixed model

$$\max_{\substack{O_t, N_{rp} \in \mathbb{Z}^* \\ s_{ait}, o_{at} \in \{0,1\}}} \sum_{p \in P} [DIS^p(\sum_{t \in T_p} (O_t \cdot v_t) - \sum_{r \in R} (N_{rp} \cdot C_{rp}))] \quad (15)$$

subject to:

$$s_{ait} \leq s_{ai(t+1)} \quad \forall a \in A, \forall i \in \mathcal{I}, \forall t \in T \quad (16)$$

$$s_{ai\sigma_{itN}} \geq 1 \quad \forall a \in A, \forall i \in I \cup M^M \quad (17)$$

$$s_{ajt} \leq s_{ai\sigma_{it}} \quad \forall a \in A, \forall (i,j) \in IP, \forall t \in T \quad (18)$$

$$N_{rp} \geq \sum_{a \in A} \sum_{i \in \mathcal{I}} (\rho_{ir} \cdot (s_{ait} - s_{ai\sigma_{it}})) \quad \forall r \in R, \forall p \in P, \forall t \in T_p \quad (19)$$

$$o_{at} \leq \frac{1}{2} \cdot (s_{aiN\sigma_{iN}t} + \sum_{i \in MU\{i_N\}} [s_{ai\sigma_{it}} - s_{ai\sigma_{i(t-\lambda_a)}}]) \quad \forall a \in A, \forall t \in T \quad (20)$$

$$O_t = \sum_{a \in A} o_{at} \quad \forall t \in T \quad (21)$$

$$N_{rp} \leq m_{rp} \quad \forall r \in R, \forall p \in P \quad (22)$$

2-Mixed Model Explanation

- (15) Objective function, sums up profits from energy made, subtracts money used on resources (vessels), and multiplies it all with a discount factor
- (16) Makes every task that is started stay started
- (17) Forces every installation and mandatory maintenance task to be started and finished by the final timestep
- (18) For every precedence relation (i, j) , ensures that i is finished before j is started
- (19) Counts up the resources needed in a time period by adding the resources needed by all tasks started, and subtracting the resources needed by all tasks finished
- (20) Sets an asset to be online if it installed and had work done on it recently
- (21) Counts how many assets are online
- (22) Sets a limit on the amount of vessels that can be chartered in a given period

Notation overview

Sets:

- P : All time periods (large scale)
- T : All time intervals (small scale) $[t_0, \dots, t_N]$
- $T_p \in T$: All time intervals (small scale) in period p
- R : All resources
- I : All installation tasks per asset $[1, \dots, i_N]$
- $M = M^M \cup M^O$: all mandatory and optional maintenance tasks
- $\mathcal{I} = I \cup M$: All tasks
- IP : All precedence pairs (i, j)
- A : All assets

Decision variables:

- O_t : Number of online turbines at timestep t
- o_{at} : Binary variable, 1 if asset a is online at timestep t
- N_{rp} : Number of resources r used in period p
- s_{ait} : Binary variable, 1 if task $i \in \mathcal{I}$ for asset a has started at or before time t

Parameters:

- DIS : The discount factor per time period
- v_t : The value of energy a single turbine produces at timestep t
- C_{rp} : The cost of chartering resource r in period p
- λ_a : The number of timesteps after the last maintenance before asset a fails
- σ_{it} : Indicates the timestep at which task i should have been started for it to be finished by timestep t , taking into account the duration and the weather conditions
- ρ_{ir} : The amount of resource r used for task $i \in \mathcal{I}$
- m_{rp} : The maximum amount of resources r that can be charatered in period p

Initial model for decommission

$$\max_{\substack{O_t, N_{rp} \in \mathbb{Z}^* \\ s_{ait}, o_{at} \in \{0,1\}}} \sum_{p \in P} [DIS^p(\sum_{t \in T_p} (O_t \cdot v_t) - \sum_{r \in R} (N_{rp} \cdot C_{rp}))] \quad (23)$$

subject to:

$$s_{ait} \leq s_{ai(t+1)} \quad \forall a \in A, \forall i \in D, \forall t \in T \quad (24)$$

$$s_{ai\sigma_{itN}} \geq 1 \quad \forall a \in A, \forall i \in D \quad (25)$$

$$s_{ajt} \leq s_{ai\sigma_{it}} \quad \forall a \in A, \forall (i,j) \in IP, \forall t \in T \quad (26)$$

$$N_{rp} \geq \sum_{a \in A} \sum_{i \in I} (\rho_{ir} \cdot (s_{ait} - s_{ai\sigma_{it}})) \quad \forall r \in R, \forall p \in P, \forall t \in T_p \quad (27)$$

$$O_t = \sum_{a \in A} (1 - s_{ai0t}) \quad \forall t \in T \quad (28)$$

$$N_{rp} \leq m_{rp} \quad \forall r \in R, \forall p \in P \quad (29)$$

Installation Model Explanation

- (23) Objective function, sums up profits from energy made, subtracts money used on resources (vessels), and multiplies it all with a discount factor
- (24) Makes every task that is started stay started
- (25) Forces every task to be started and finished by the final timestep
- (26) For every precedence relation (i, j) , ensures that i is finished before j is started
- (27) Counts up the resources needed in a time period by adding the resources needed by all tasks started, and subtracting the resources needed by all tasks finished
- (28) Counts the number of turbines which have not started decommissioning by a given timestep
- (29) Sets a limit on the amount of vessels that can be charatered in a given period

Notation overview

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- T : All time intervals (small scale)
 $[t_0, \dots, t_N]$
- $T_p \in T$: All time intervals (small scale)
in period p
- R : All resources
- D : All tasks per asset $[i_0, \dots, i_N]$
- IP : All precedence pairs (i, j)
- A : All assets

Decision variables:

- O_t : Number of online turbines at
timestep t
- N_{rp} : Number of resources r used in
period p
- s_{ait} : Binary variable, 1 if task $i \in I$ for
asset a has started at or before time t

Parameters:

- DIS : The discount factor per period
- v_t : The value of energy a single turbine
produces in timestep t
- C_{rp} : The cost of chartering resource r
in period p
- σ_{it} : Indicates the timestep at which
task i should have been started for it to
be finished by timestep t , taking into
account the duration and the weather
conditions
- ρ_{ir} : The amount of resource r used by
task i
- t_p : The final time interval (from T)
before period p
- m_{rp} : The maximum amount of
resources r that can be chartered in
period p

Initial 3-mixed model

$$\max_{\substack{O_t, N_{rp} \in \mathbb{Z}^* \\ s_{ait}, o_{at} \in \{0,1\}}} \sum_{p \in P} [DIS^p(\sum_{t \in T_p} (O_t \cdot v_t) - \sum_{r \in R} (N_{rp} \cdot C_{rp}))] \quad (30)$$

subject to:

$$s_{ait} \leq s_{ai(t+1)} \quad \forall a \in A, \forall i \in \mathcal{I}, \forall t \in T \quad (31)$$

$$s_{ai\sigma_{itN}} \geq 1 \quad \forall a \in A, \forall i \in I \cup M^M \cup D \quad (32)$$

$$s_{ajt} \leq s_{ai\sigma_{it}} \quad \forall a \in A, \forall (i,j) \in IP, \forall t \in T \quad (33)$$

$$N_{rp} \geq \sum_{a \in A} \sum_{i \in \mathcal{I}} (\rho_{ir} \cdot (s_{ait} - s_{ai\sigma_{it}})) \quad \forall r \in R, \forall p \in P, \forall t \in T_p \quad (34)$$

$$o_{at} \leq \frac{1}{2} \cdot (s_{aiN\sigma_{itN}} + \sum_{i \in MU \setminus \{i_N\}} [s_{ai\sigma_{it}} - s_{ai\sigma_{i(t-\lambda_a)}}] - s_{ai_0^d t}) \quad \forall a \in A, \forall t \in T \quad (35)$$

$$O_t = \sum_{a \in A} o_{at}$$

3-Mixed Model Explanation

- (15) Objective function, sums up profits from energy made, subtracts money used on resources (vessels), and multiplies it all with a discount factor
- (16) Makes every task that is started stay started
- (17) Forces every installation and mandatory maintenance task to be started and finished by the final timestep
- (18) For every precedence relation (i, j) , ensures that i is finished before j is started
- (19) Counts up the resources needed in a time period by adding the resources needed by all tasks started, and subtracting the resources needed by all tasks finished
- (20) Sets an asset to be online if it installed and had work done on it recently
- (21) Counts how many assets are online
- (22) Sets a limit on the amount of vessels that can be chartered in a given period

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- $\mathcal{I} = I \cup M$: All tasks
- IP : All precedence pairs (i, j)
- A : All assets

Decision variables:

- O_t : Number of online turbines at timestep t
- o_{at} : Binary variable, 1 if asset a is online at timestep t
- N_{rp} : Number of resources r used in period p
- s_{ait} : Binary variable, 1 if task $i \in \mathcal{I}$ for asset a has started at or before time t

Parameters:

- DIS : The discount factor per time period
- v_t : The value of energy a single turbine produces at timestep t
- C_{rp} : The cost of chartering resource r in period p
- λ_a : The number of timesteps after the last maintenance before asset a fails
- σ_{it} : Indicates the timestep at which task i should have been started for it to be finished by timestep t , taking into account the duration and the weather conditions
- ρ_{ir} : The amount of resource r used for task $i \in \mathcal{I}$
- m_{rp} : The maximum amount of resources r that can be charatered in period p