Optimizing Offshore Wind Farm Design

Team 9
산업경영공학부 2013170811 이성계
산업경영공학부 2014170810 김기호

최적화응용 Term Project
Fall semester 2019

Contents

Contents

1 About System

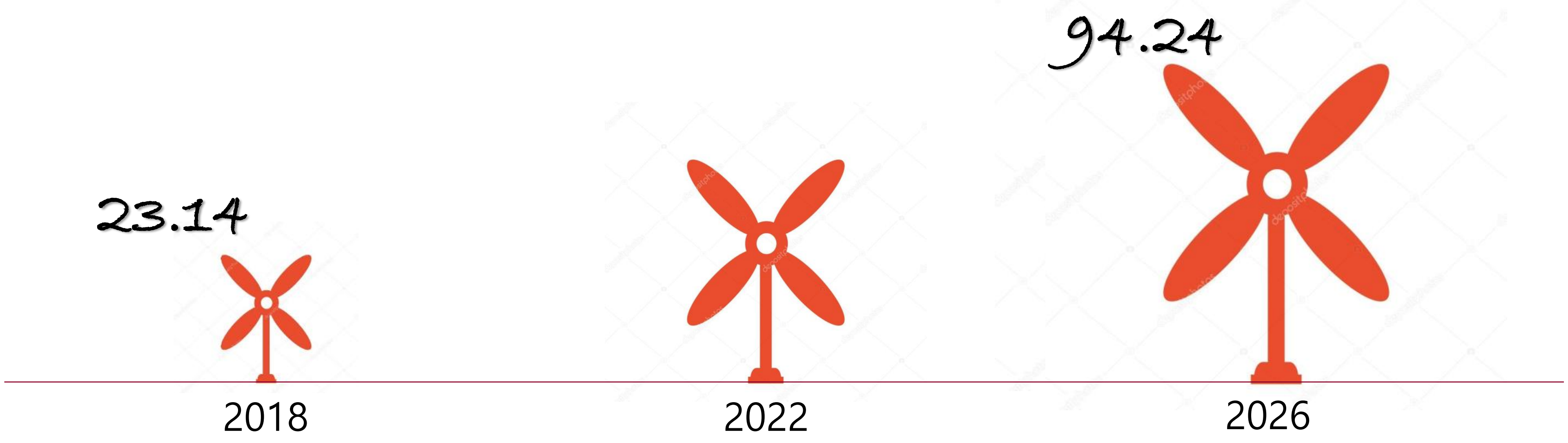
Offshore Wind Farm Design

01
Turbine Layout

02
Cable Routing

1 About System

Why to optimize it : Floating Offshore Wind Power Market



단위: GW (gigawatt)

Contents

2

1) Turbine Layout – modeling analysis

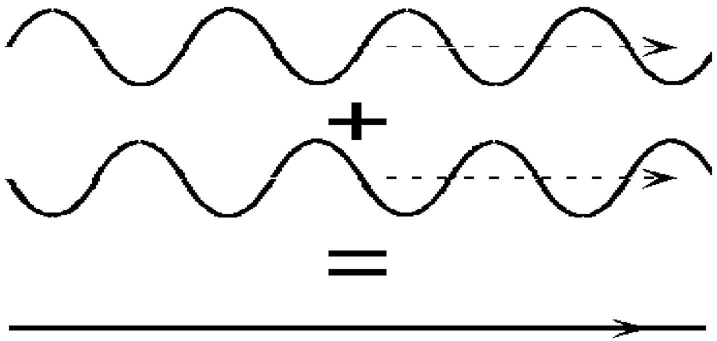
What to optimize : Turbin Layout

2

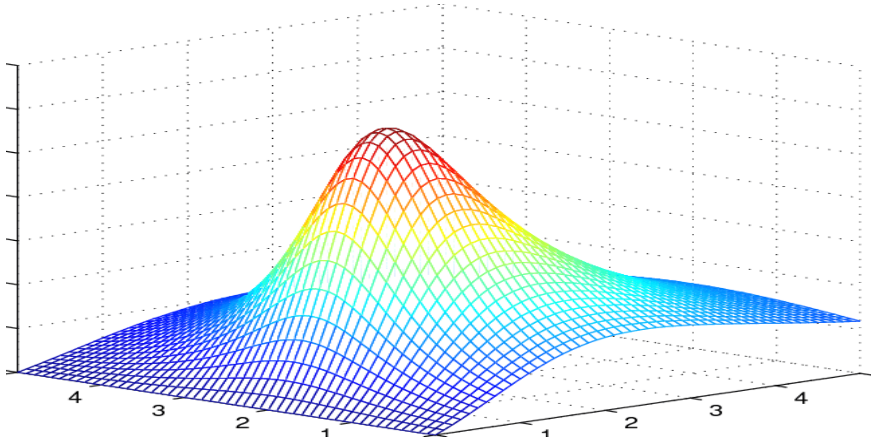
1) Turbine Layout – modeling analysis

Considerations

◇ Power loss by interference (Wake Effect)



◇ Maximize power



2 1) Turbine Layout – modeling analysis

How to optimize real-problem

To solve 20,000+ possible positions

Optimal Solution

Mixed Integer
Linear Programming
Proximity Search

Initial Solution
Ad-hoc Heuristic

How to optimize real-problem – 1) Ad-hoc Heuristic

To solve 20,000+ possible positions

Optimal Solution

Mixed Integer
Linear Programming
Proximity Search

Initial Solution
Ad-hoc Heuristic

2 1) Turbine Layout – modeling analysis

Ad-hoc Heuristic (iter 0)

	1
	0

X1	X2	X3	X4	X5	X6	X7	X8

2 1) Turbine Layout – modeling analysis

Ad-hoc Heuristic (iter 1, improved)

	1
	0

X1	X2	X3	X4	X5	X6	X7	X8

Ad-hoc Heuristic (iter 2 , improved)

	1
	0

X1	X2	X3	X4	X5	X6	X7	X8

2 1) Turbine Layout – modeling analysis

Ad-hoc Heuristic (iter 3 , improved)

	1
	0

X1	X2	X3	X4	X5	X6	X7	X8

Ad-hoc Heuristic (iter 4, not improved)

	1
	0

X1	X2	X3	X4	X5	X6	X7	X8

2

1) Turbine Layout – modeling analysis

Ad-hoc Heuristic (iter 4, not improved)

(dark red)	1
(light grey)	0

Initial Solution!

X1	X2	X3	X4	X5	X6	X7	X8
0	0	1	1	1	1	0	0

2 1) Turbine Layout – modeling analysis

Ad-hoc Heuristic

Maximize. δj + FLIP(j)

$$\delta_j = \begin{cases} P_j - \sum_{i \in V: x_i = 1} (I_{ij} + I_{ji}) & \text{if } x_j = 0; \\ -P_j + \sum_{i \in V: x_i = 1} (I_{ij} + I_{ji}) & \text{if } x_j = 1 \end{cases}$$

Profit by flip

$$FLIP(j) = \begin{cases} -HUGE & \text{if } x_j = 0 \text{ and } \gamma \geq n_2 \\ -HUGE & \text{if } x_j = 1 \text{ and } \gamma \leq n_1 \\ +HUGE & \text{if } x_j = 0 \text{ and } \gamma < n_1 \\ +HUGE & \text{if } x_j = 1 \text{ and } \gamma > n_2 \\ 0 & \text{otherwise} \end{cases}$$

Bound Constraints

How to optimize real-problem – 2) Mixed Integer Linear programming

To solve 20,000+ possible positions

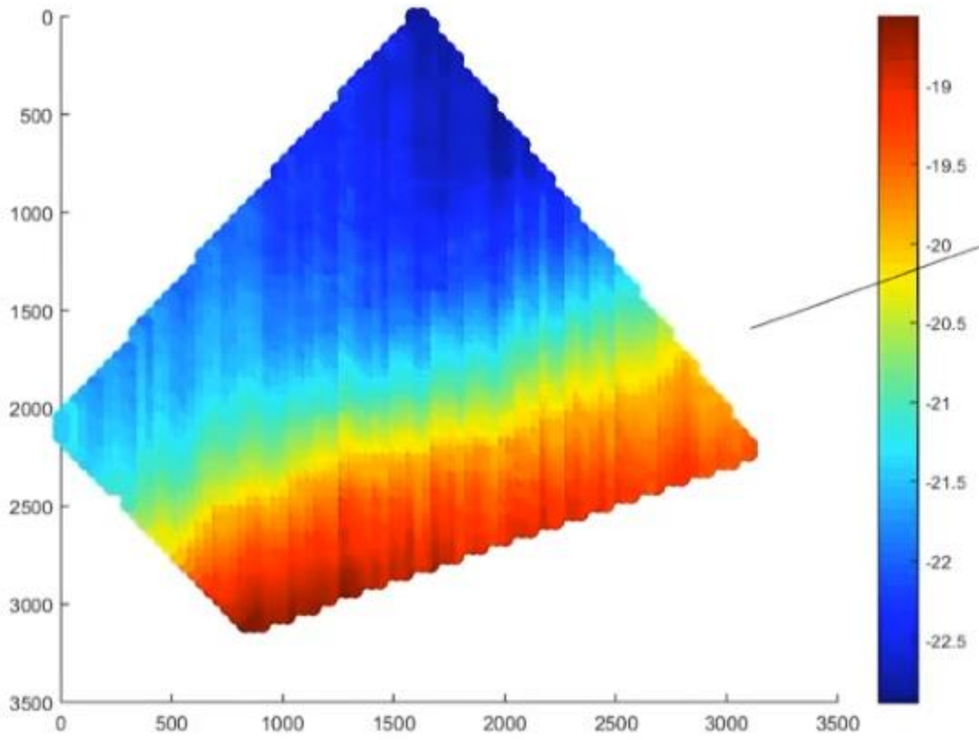
Optimal Solution

Mixed Integer
Linear Programming
Proximity Search

Initial Solution
Ad-hoc Heuristic
MILP-based Heuristic (Proximity Search)

2 1) Turbine Layout – modeling analysis

Mixed Integer Linear programming - Discretization



The layout problem can be formulated as a MIP problem.
Variables:

$$x_i = \begin{cases} 1 & \text{if a turbine is built at position } i \in V; \\ 0 & \text{otherwise} \end{cases} \qquad (i \in V)$$

where V is the set of potential turbine positions.

Mixed Integer Linear programming – Stochastic Programming

$$P_i := \sum_{k=1}^{K} \pi_k P_i^k \qquad \forall i \in V$$

$$I_{ij} := \sum_{k=1}^{K} \pi_k I_{ij}^k \qquad \forall i, j \in V$$

2 1) Turbine Layout – modeling analysis

Mixed Integer Linear programming – Quadratic Assignment

$$\sum_{i\in V} P_i x_i - \sum_{i\in V} (\sum_{j\in V} I_{ij} x_j)\, x_i$$

Third-Order

$$\sum_{i\in V} (P_i x_i - w_i)$$

$$w_i := (\sum_{j\in V} I_{ij} x_j)\, x_i = \begin{cases} \sum_{j\in V} I_{ij} x_j & \text{if } x_i = 1; \\ 0 & \text{if } x_i = 0. \end{cases}$$

Second-Order

Mixed Integer Linear programming – Quadratic Assignment

$$\sum_{i\in V}(P_i x_i - w_i)$$

$$\sum_{i\in V} P_i x_i - \sum_{i\in V}\big(\sum_{j\in V} I_{ij}x_j\big)\, x_i$$

Third-Order

$$w_i := \big(\sum_{j\in V} I_{ij}x_j\big)\, x_i = \begin{cases} \sum_{j\in V} I_{ij}x_j & \text{if } x_i = 1; \\ 0 & \text{if } x_i = 0. \end{cases}$$

Second-Order

2 1) Turbine Layout – modeling analysis

Mixed Integer Linear programming – Proximity Search

$$\sum_{i \in V}(P_i x_i - w_i) \geq \sum_{i \in V}(P_i \tilde{x}_i - \tilde{w}_i) + \theta$$

- Constraints (by θ)

$$\Delta(x, \tilde{x}) = \sum_{j \in V : \tilde{x}_j = 0} x_j + \sum_{j \in V : \tilde{x}_j = 1} (1 - x_j)$$

- Objective Function

- Minimize Proximity

How to optimize real-problem

To solve 20,000+ possible positions

Optimal Solution

Mixed Integer
Linear Programming

Initial Solution

Ad-hoc Heuristic
MILP-based Heuristic (Proximity Search)

2 2) Turbine Layout – discussion

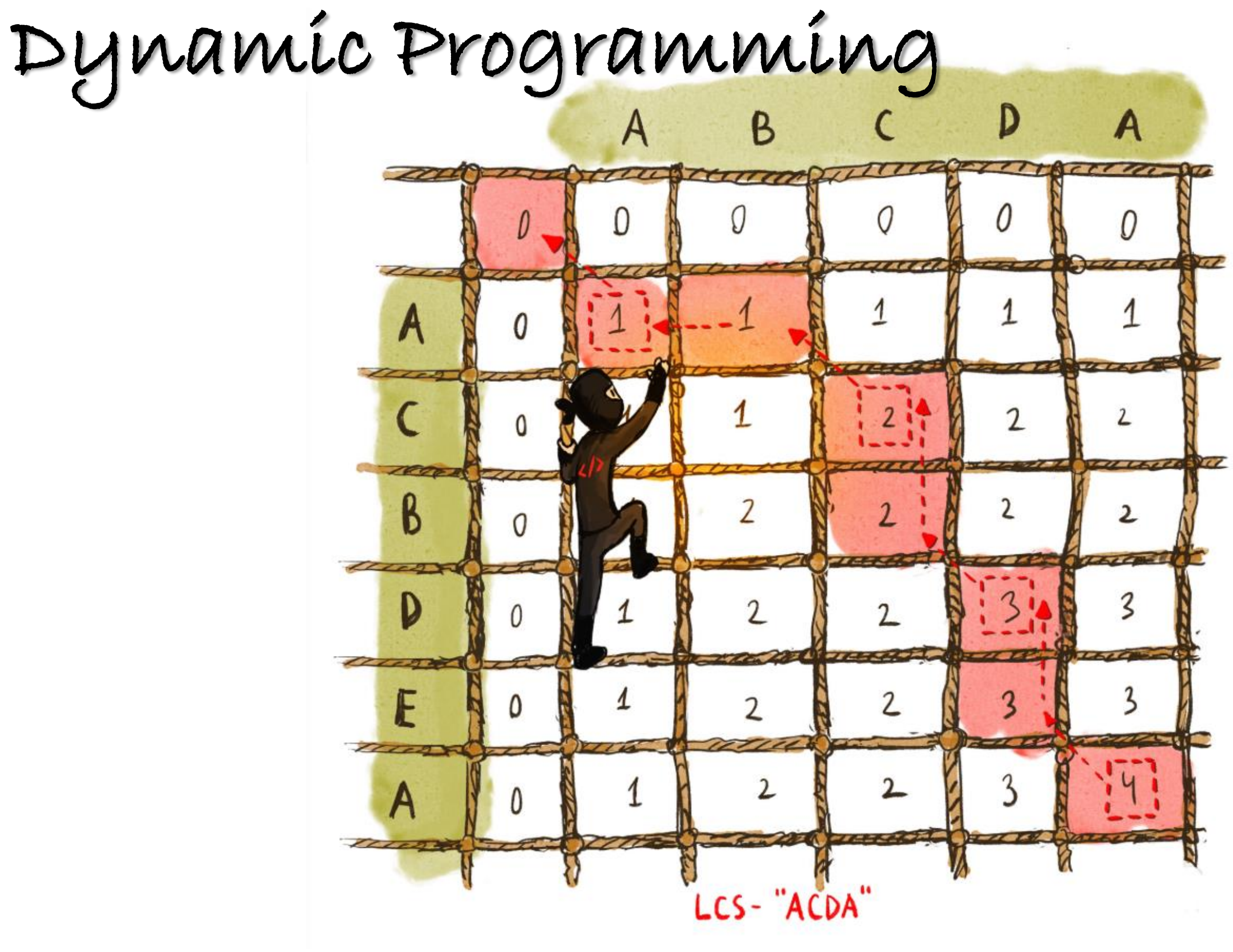
What is different?

기존 모델 VS 해당 모델

기존 모델	해당 모델
1000+ possible positions	20000+ possible positions
~~Wind Variability~~	Wind Variability

2 2) Turbine Layout – discussion

Criticism : So many heuristic



Contents

1) Cable Routing – modeling analysis

What to optimize? – set and decision variables

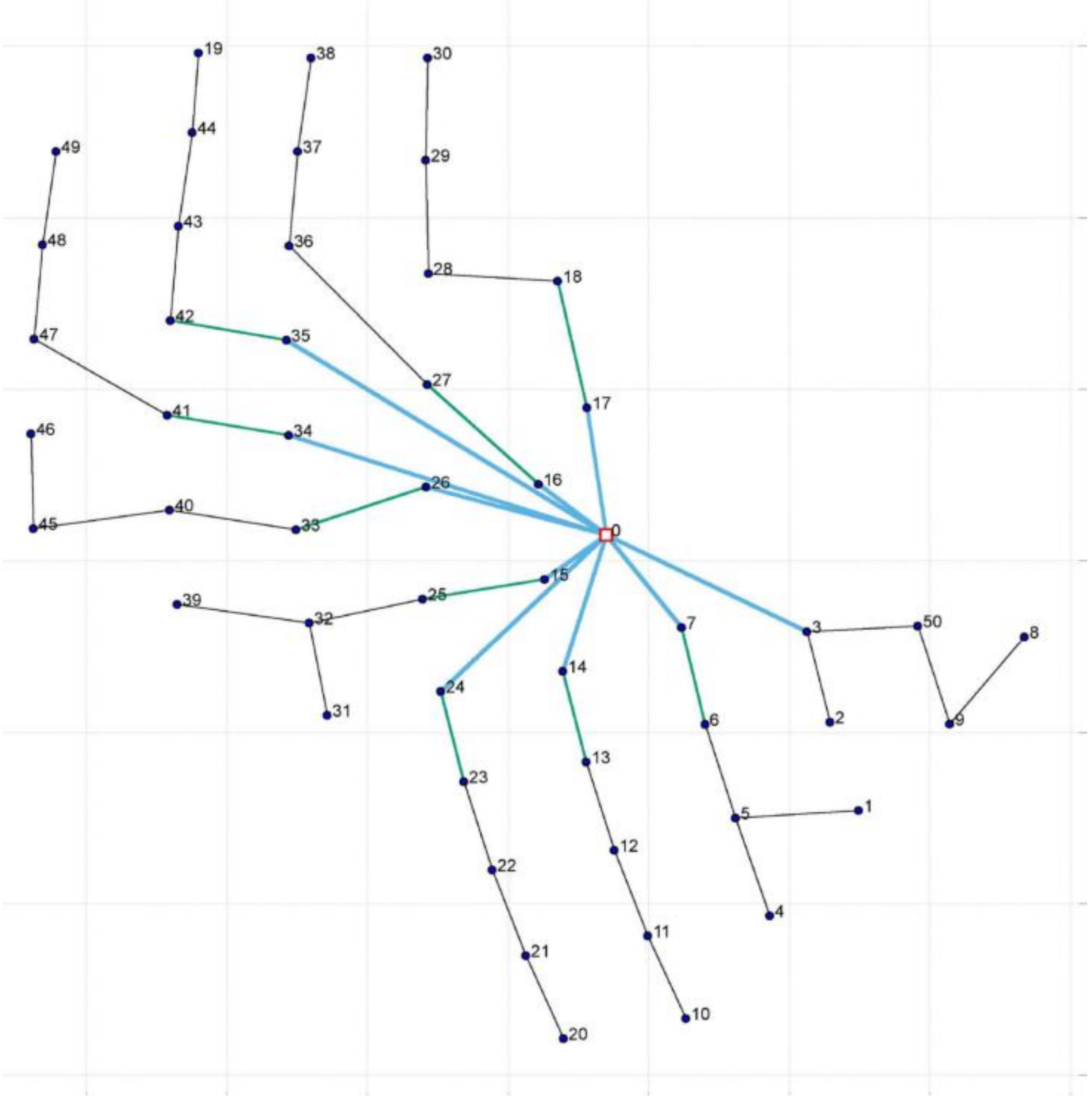
V: 전체 $node$의 집합

V_T : $Turbine\ node$

V_O : $Substation\ node$

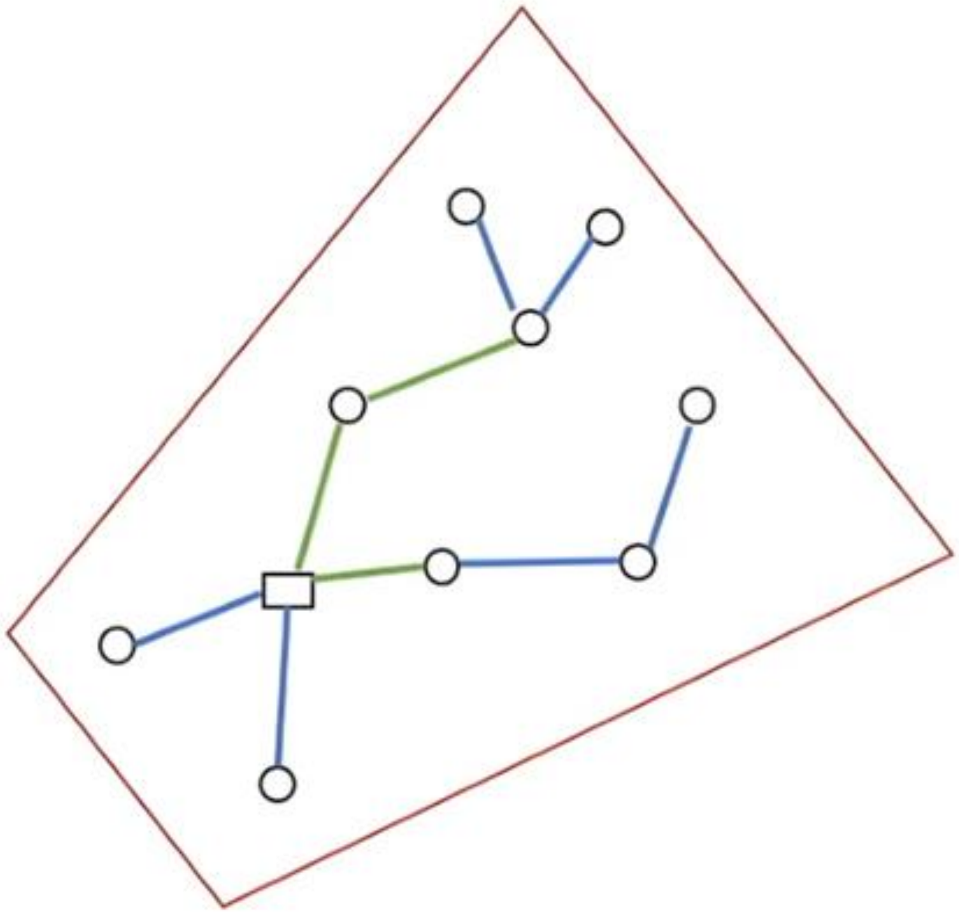
V_S : $Steiner\ node$

$$V = V_T \cup V_O \cup V_S$$



3 1) Cable Routing – modeling analysis

What to optimize? – set and decision variables



VARIABLES (on the arcs):

$f_{i,j} \geq 0$ is the flow (current) from i to j

$$x^t_{i,j} = \begin{cases} 1 & \text{if arc } (i,j) \text{ is built with cable } t \\ 0 & \text{otherwise} \end{cases}$$

$y_{i,j} = 1$ if an arc from i to j is built,
with any type of cable ($\sum_{t \in T} x^t_{ij} = y_{ij}$)

What to optimize? – basic model

$$\min \sum_{(i,j)\in A} \sum_{t\in T} c^t_{i,j} x^t_{i,j}$$

비용 최소화

$$\sum_{t\in T} x^t_{i,j} = y_{i,j}, \qquad (i,j) \in A$$

주어진 케이블 종류 외의 케이블은 사용 불가

$$\sum_{i\in V: i\neq h} (f_{h,i} - f_{i,h}) = P_h, \qquad h \in V_T \cup V_S$$

전하량 보존

$$\sum_{t\in T} k_t\, x^t_{i,j} \geq f_{i,j}, \qquad (i,j) \in A$$

케이블에 흐르는 전류는 capacity를 넘길 수 없음

What to optimize? – basic model

$$\sum_{j \in V: j \neq h} y_{h,j} = 1, \qquad h \in V_T$$

모든 Turbine에 1개의 케이블이 연결

$$\sum_{j \in V: j \neq h} y_{h,j} = 0, \qquad h \in V_0$$

발전소에서 나가는 전류가 없어야 함

$$\sum_{j \in V: j \neq h} y_{h,j} \leq 1, \qquad h \in V_S$$

$$\sum_{i \in V: i \neq h} y_{i,h} \leq 1, \qquad h \in V_S$$

Steiner node에는 케이블이 1개 이하로 연결

$$\sum_{i \in V: i \neq h} y_{i,h} \leq C, \qquad h \in V_0$$

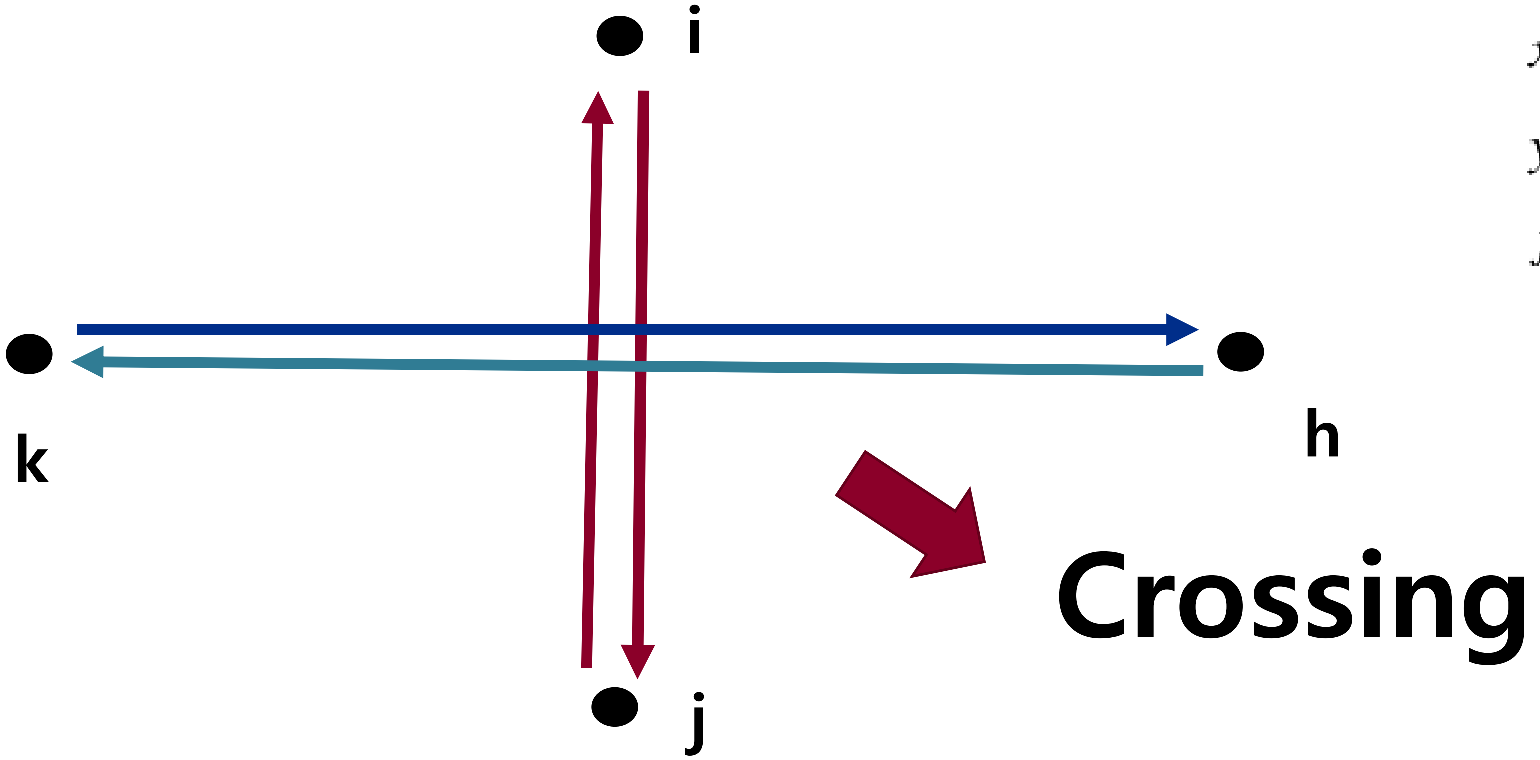
발전소에 연결할 수 있는 최대 케이블의 수

What to optimize? – basic model

$$y_{i,j} + y_{j,i} + y_{h,k} + y_{k,h} \leq 1, \qquad \text{for all crossing segments } [i,j] \text{ and } [h,k]$$

케이블 끼리 교차하지 않아야 한다.

$$x^t_{i,j} \in \{0,1\}, (i,j) \in A, t \in T$$
$$y_{i,j} \in \{0,1\}, (i,j) \in A$$
$$f_{i,j} \geq 0, (i,j) \in A.$$



3 1) Cable Routing – modeling analysis

What to optimize? – Branching penalty model

$$\min \sum_{(i,j)\in A} \sum_{t\in T} c^t_{i,j} x^t_{i,j} + \sum_{d\in D} \pi_d \sum_{j\in V_T} z^d_j$$

$$\sum_{i\in V: i\neq j} y_{i,j} = \sum_{d\in D} d\, z^d_j, \quad j \in V_T$$

$$\sum_{d\in D} z^d_j \leq 1, \qquad j \in V_T$$

$$D = \{1, .. d_{\max}\}$$

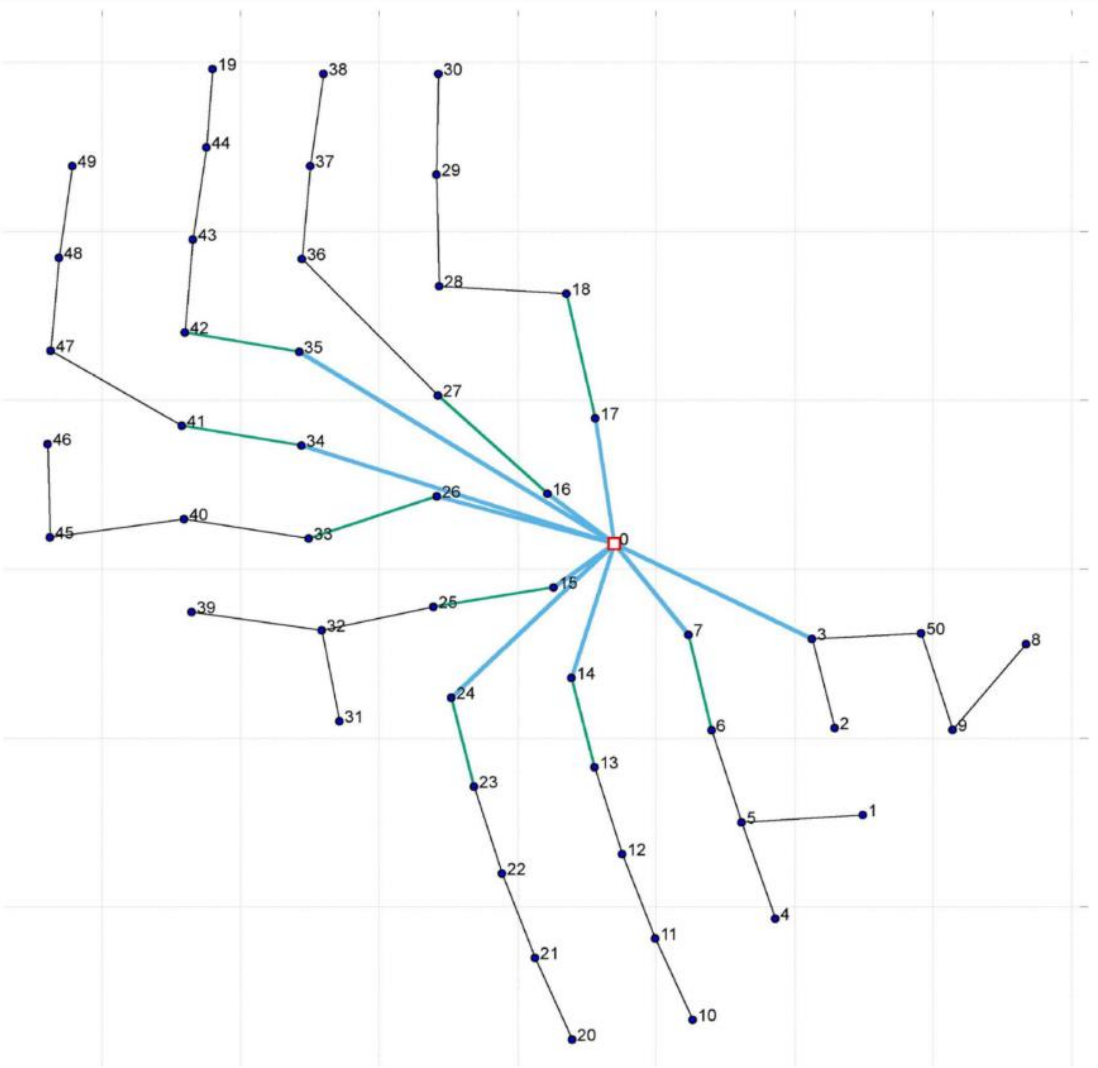
π_d : branching으로 인한 extra fee

$$\pi_1 = 0\,, \pi_2 = 25\,k£$$

z^d_j with $j \in V_T$ and $d \in D$

$z^d_j = 1$ node j의 가지 갯수가 d인 경우

$z^d_j = 0$ node j의 가지 갯수가 d가 아닌 경우



3 1) Cable Routing – modeling analysis

What to optimize? – 3) closed loop model

$q_{i,j} = 0$ node i, j 에 redundant 케이블이 연결 되지 않는 경우

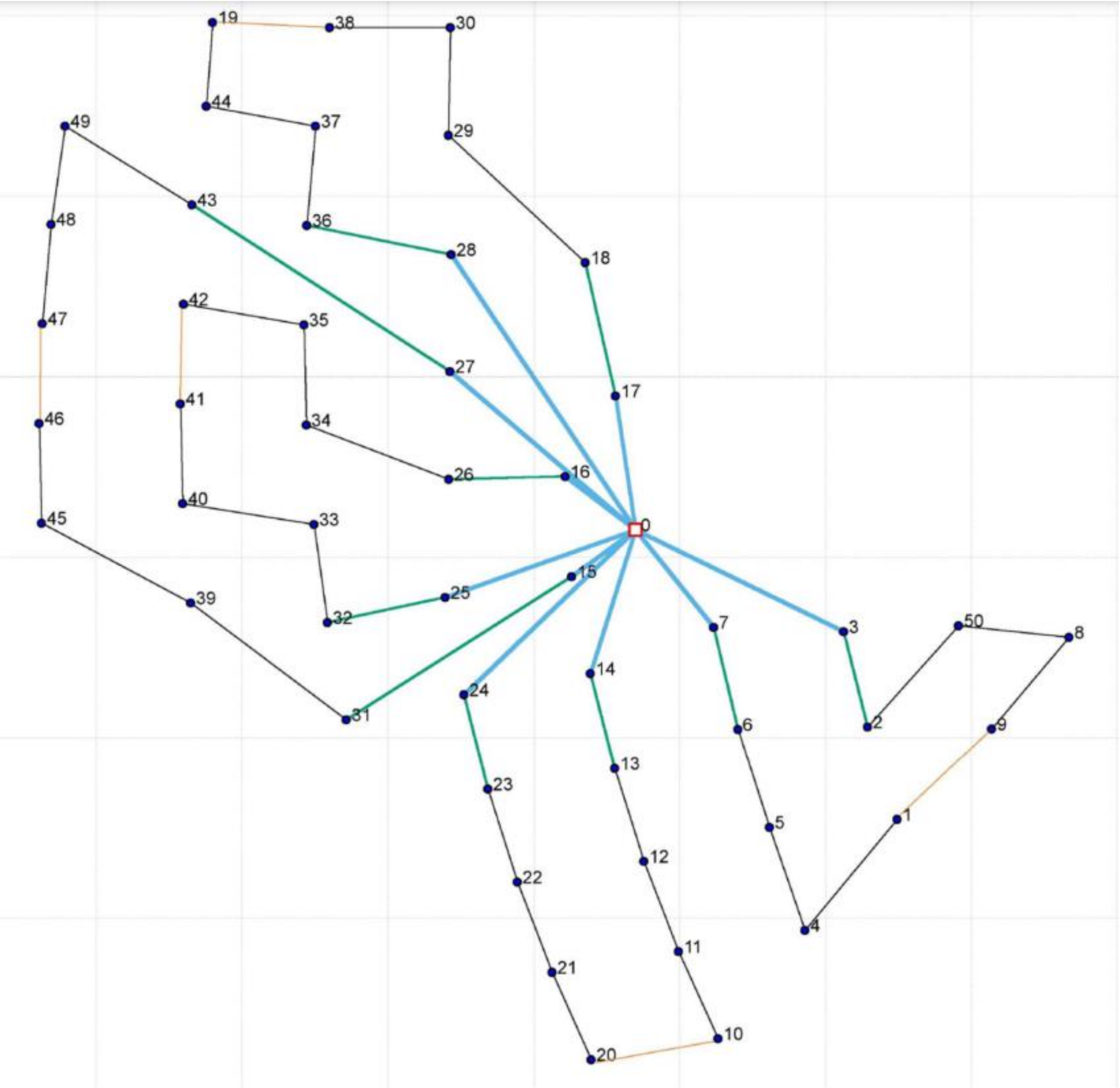
$q_{i,j} = 1$ node i, j 에 redundant 케이블이 연결 되는 경우

$$q_{i,j} = 0, \qquad (i,j) \in A : i > j$$

$$q_{i,j} \in \{0, 1\}, \qquad (i,j) \in A$$

$$\min \sum_{(i,j)\in A} \sum_{t\in T} c^t_{i,j} x^t_{i,j} + \sum_{(i,j)\in A} c^{t_{\min}}_{i,j} q_{i,j}$$

$$\sum_{i\in V: i\neq h} (y_{i,h} + y_{h,i} + q_{i,h} + q_{h,i}) = 2 \sum_{j\in V: j\neq h} y_{h,j}, \qquad h \in V_T \cup V_S$$



Criticism

전력손실을 제약식에 고려하지 않음

$$\sum_{i \in V : i \neq h} (f_{h,i} - f_{i,h}) = P_h, \qquad h \in V_T \cup V_S \quad \Rightarrow \quad \sum_{i \in V : i \neq h} (f_{h,i} - f_{i,h}) = P_h - \underline{(f_{i,h})^2 r_t}$$

Extra branching cost의 지나친 단순화

$\pi_1 = 0, \pi_2 = 25\,k£$ ⇒ 각 노드의 위치에 따른 특성에 대한 고려 없이 branching cost를 상수로 고정함

Branching의 개수를 2로 제한

$D = \{1, .. d_{\max}\}$, $d_{\max} \leq 2$ ⇒ $d_{\max}$ 의 값을 다양화 하여 더 많은 니즈를 충족 가능

감사합니다