

Automatic Design of Aircraft Arrival Routes with Limited Turning Angle

Tobias Andersson Granberg, Tatiana Polishchuk, Valentin Polishchuk, **Christiane Schmidt**

Introduction: Air transportation, SIDs + STARs

Grid-based IP formulation

Experimental Study: Arlanda Airport

Conclusion/Outlook

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 - ◉ avoid creating conflict points



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Standard Instrument Departures (SIDs) and
Standard Terminal Arrival Routes (STARs)

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STAR–SID crossings far from the runway,
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vertically (difference of descend and climb slopes)

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Pareto frontier of multicriteria optimization problem:
set of Pareto optimal solutions (cannot be improved with respect to one of the objectives without sacrificing on the other)

Grid-based IP formulation

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- IP formulation is based on flow IP formulation for Steiner trees (Min Cost Flow Steiner arborescence)

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$$\sum_{k:(k,i) \in E} f_{ki} - \sum_{j:(i,j) \in E} f_{ij} = \begin{cases} |\mathcal{P}| & i = r \\ -1 & i \in \mathcal{P} \\ 0 & i \in V \setminus \{\mathcal{P} \cup r\} \end{cases}$$

$$x_e \geq \frac{f_e}{N} \quad \forall e \in E$$

$$f_e \geq 0 \quad \forall e \in E$$

$$x_e \in \{0, 1\} \quad \forall e \in E$$

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$$\min \sum_{e \in E} \ell_e f_e \quad (1)$$

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Degree constraints:

$$\sum_{k:(k,i) \in E} x_{ki} \leq 2 \quad \forall i \in V \setminus \{\mathcal{P} \cup r\}$$

$$\sum_{j:(i,j) \in E} x_{ij} \leq 1 \quad \forall i \in V \setminus \{\mathcal{P} \cup r\}$$

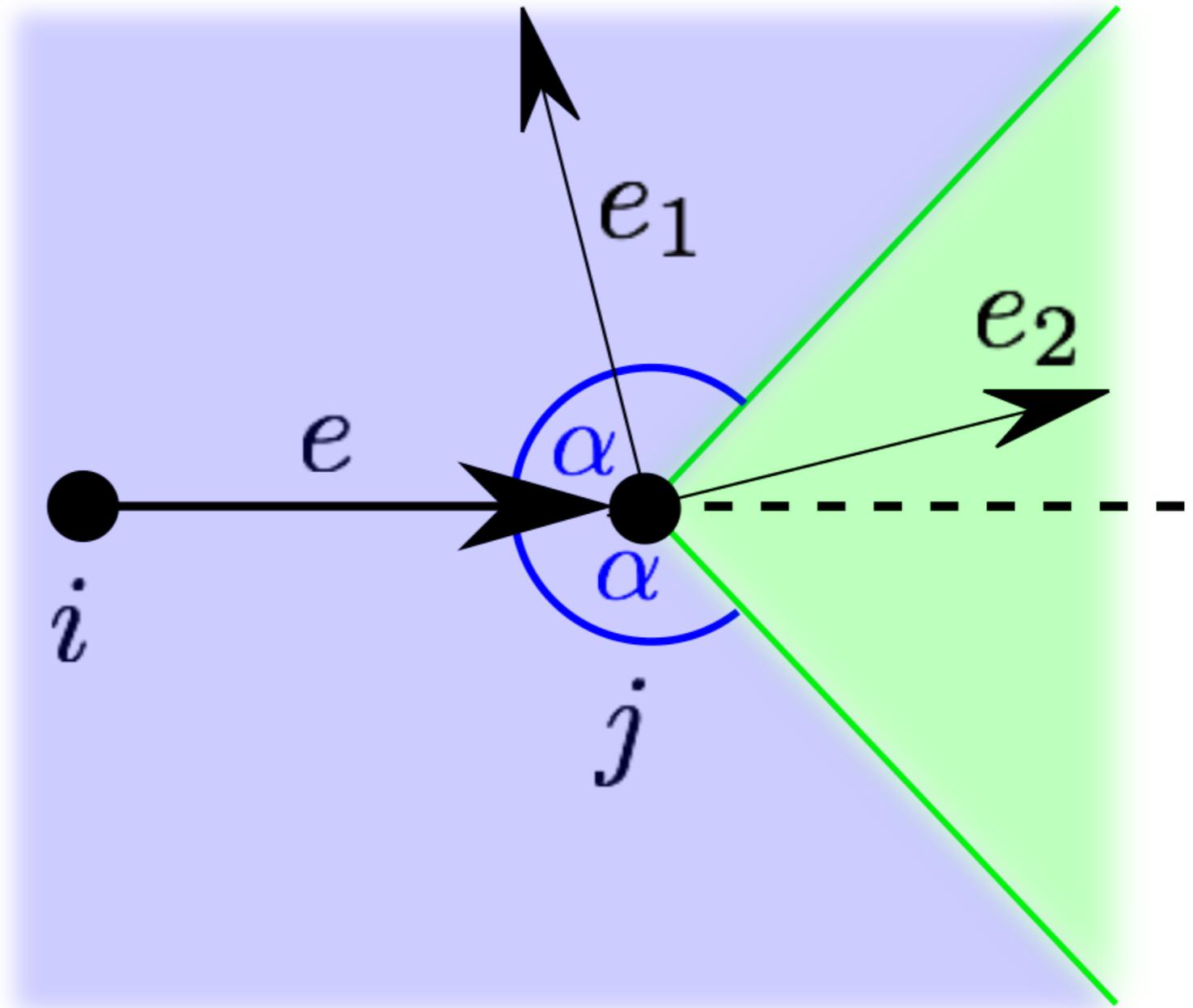
$$\sum_{k:(k,r) \in E} x_{kr} = 1$$

$$\sum_{j:(r,j) \in E} x_{rj} \leq 0$$

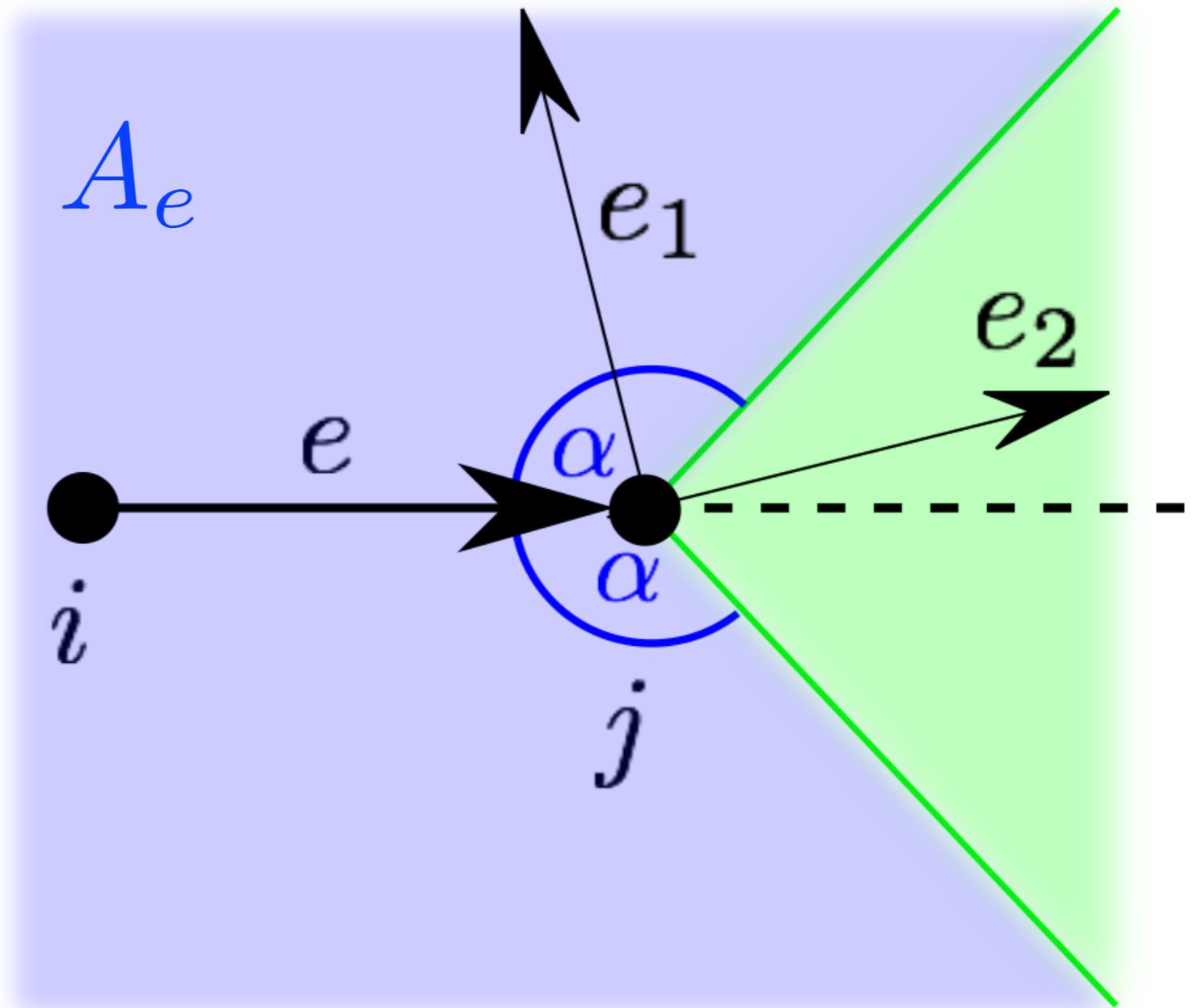
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Turn angle constraints:

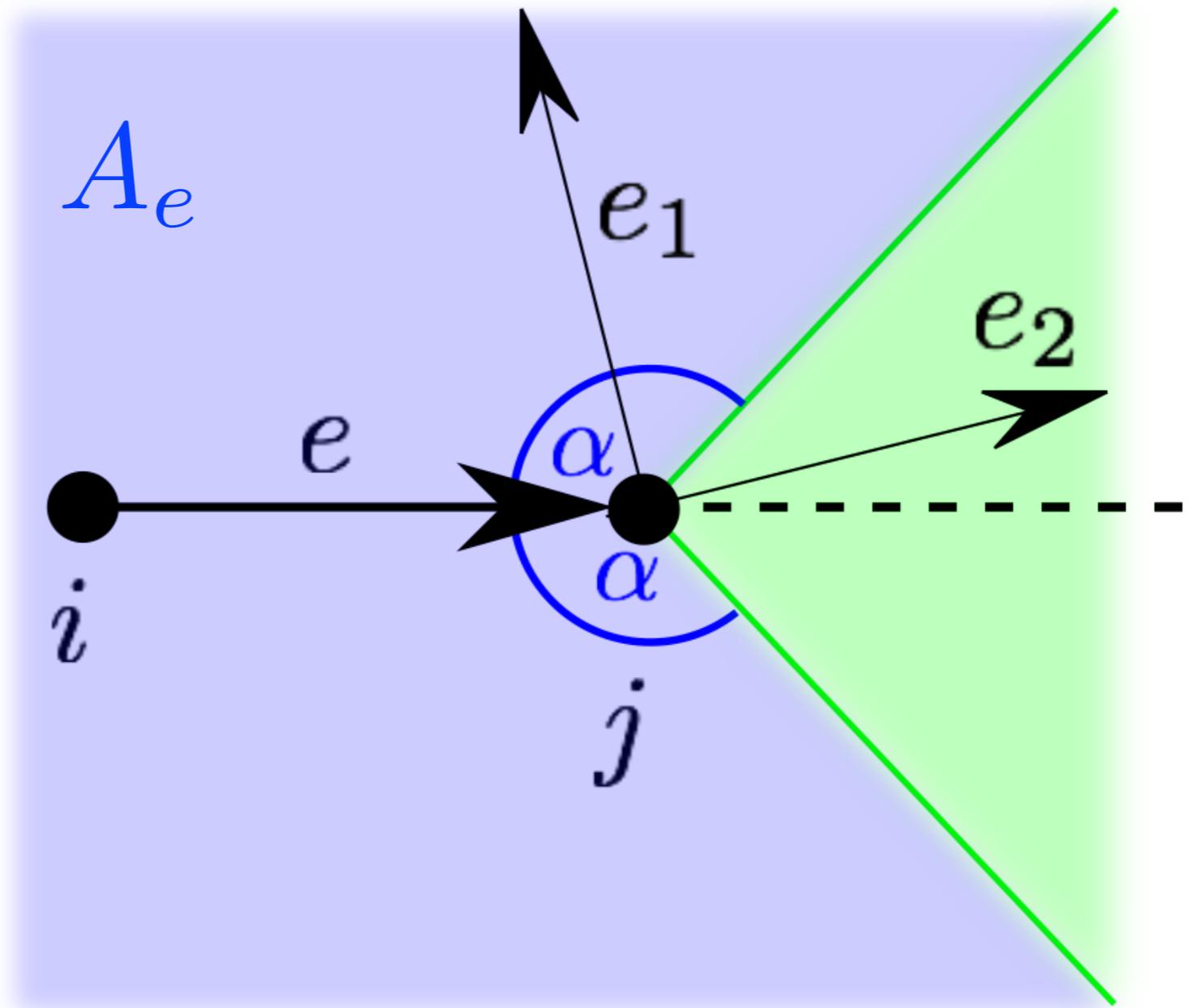


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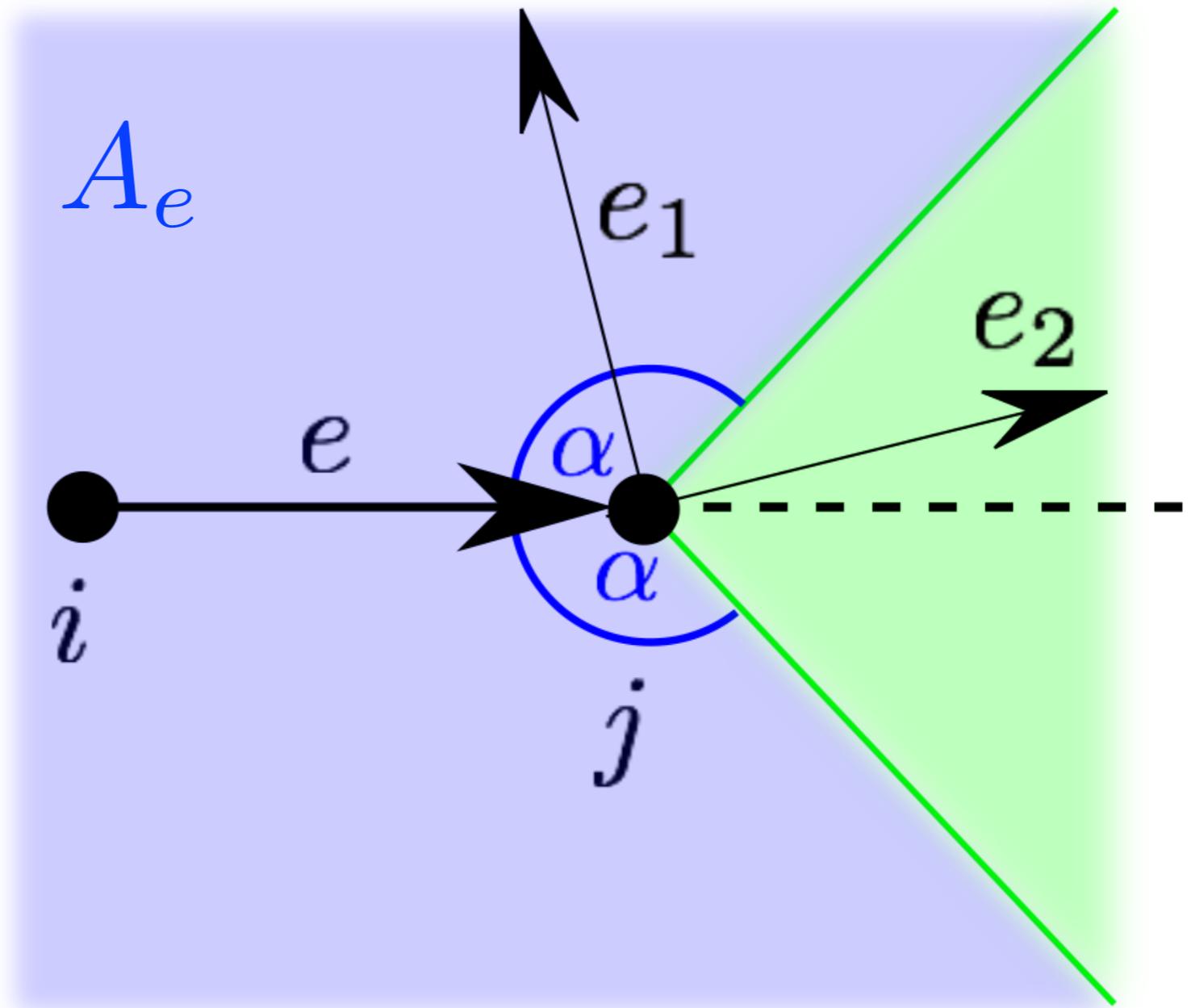
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$$a_e x_e + \sum_{f \in A_e} x_f \leq a_e \quad \forall e \in E$$

SID constraints:

We disallow STAR edges to intersect SID edges within distance d from the runway.

Experimental Study: Arlanda Airport

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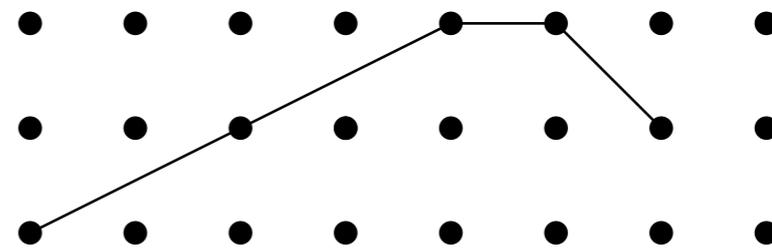
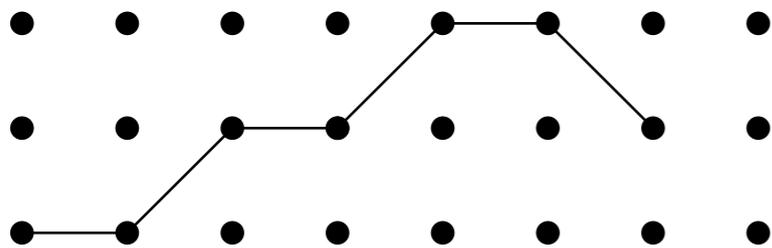
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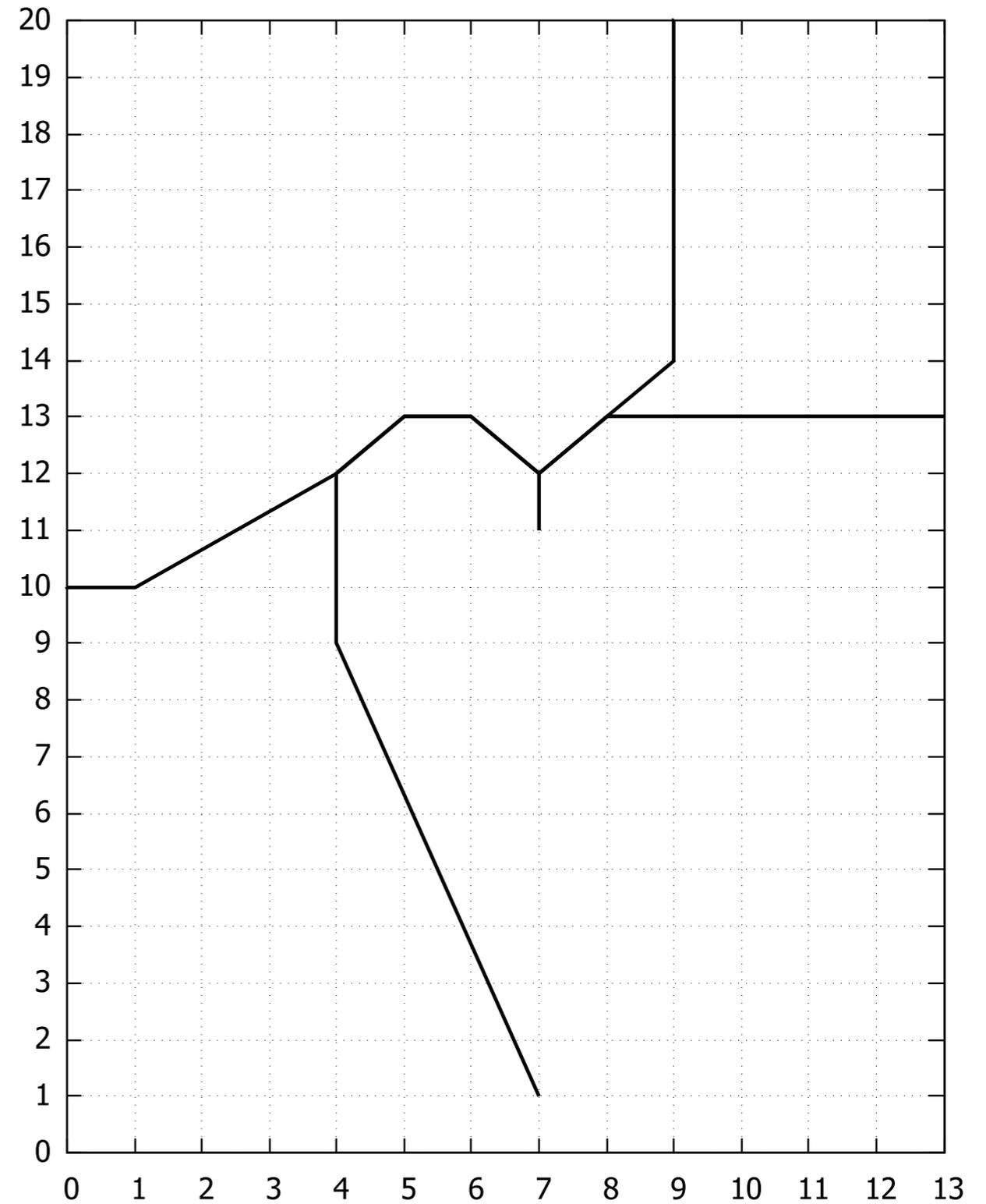
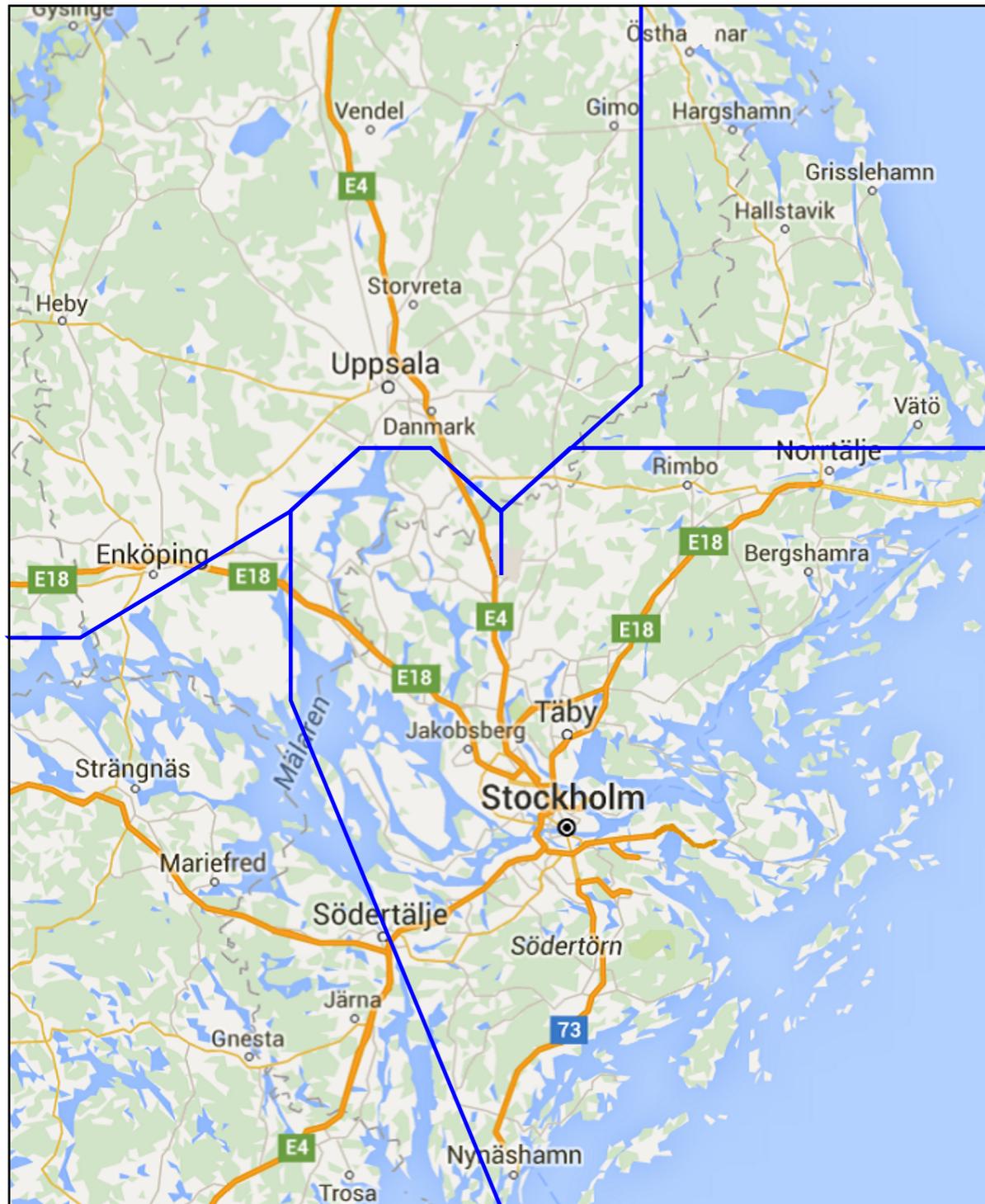
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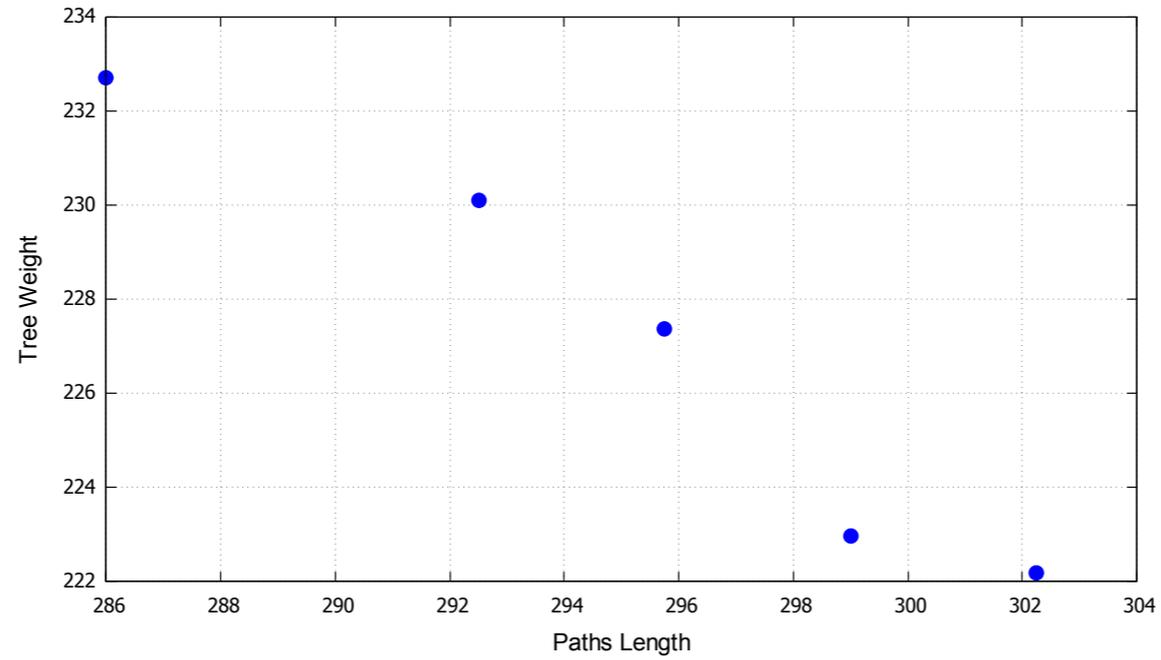
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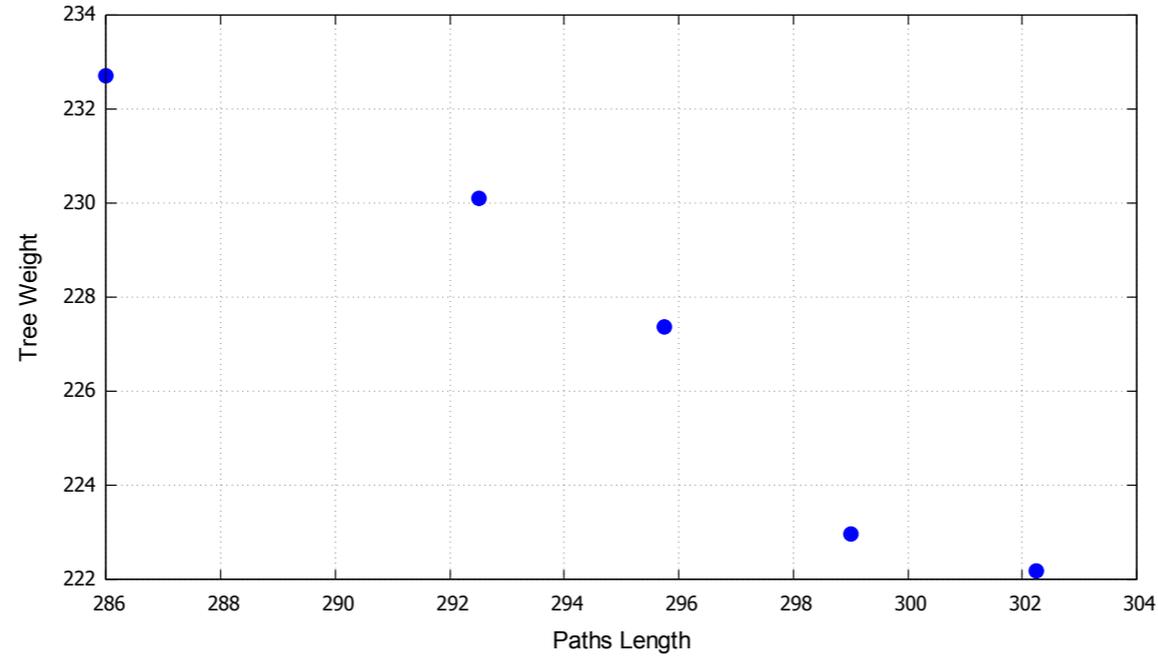




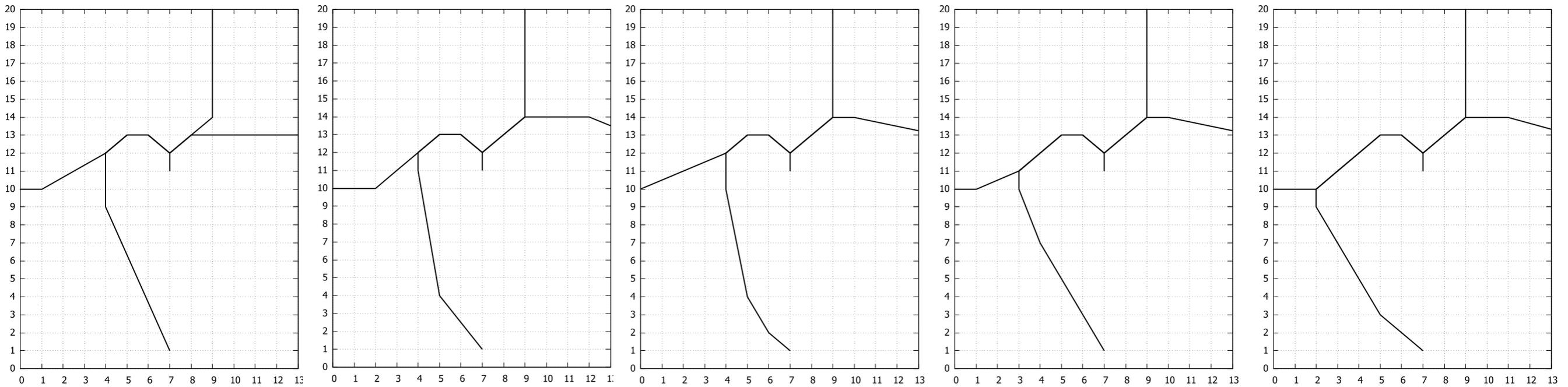
Pareto frontier:



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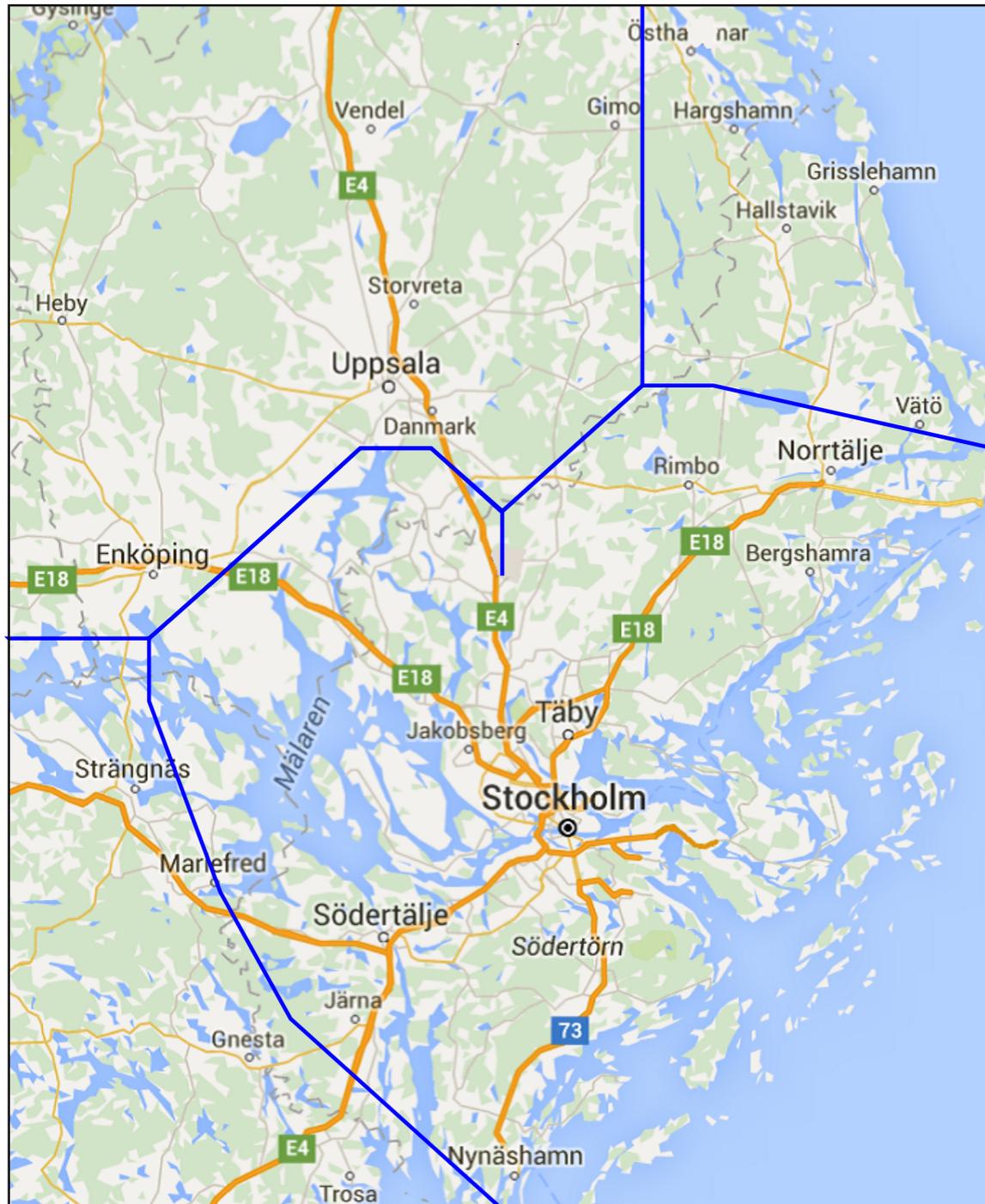


Pareto optimal solutions:

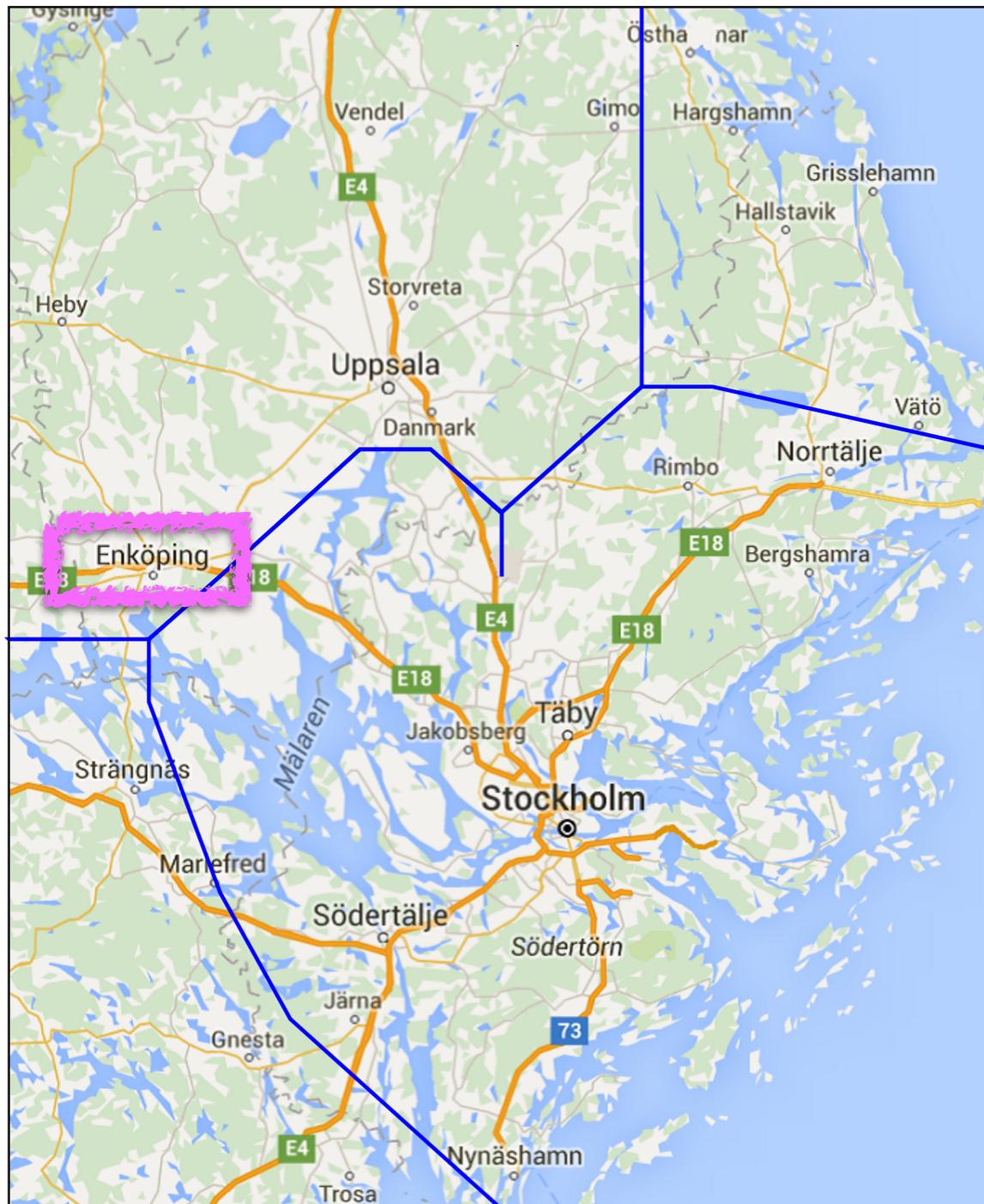


Obstacle avoidance:

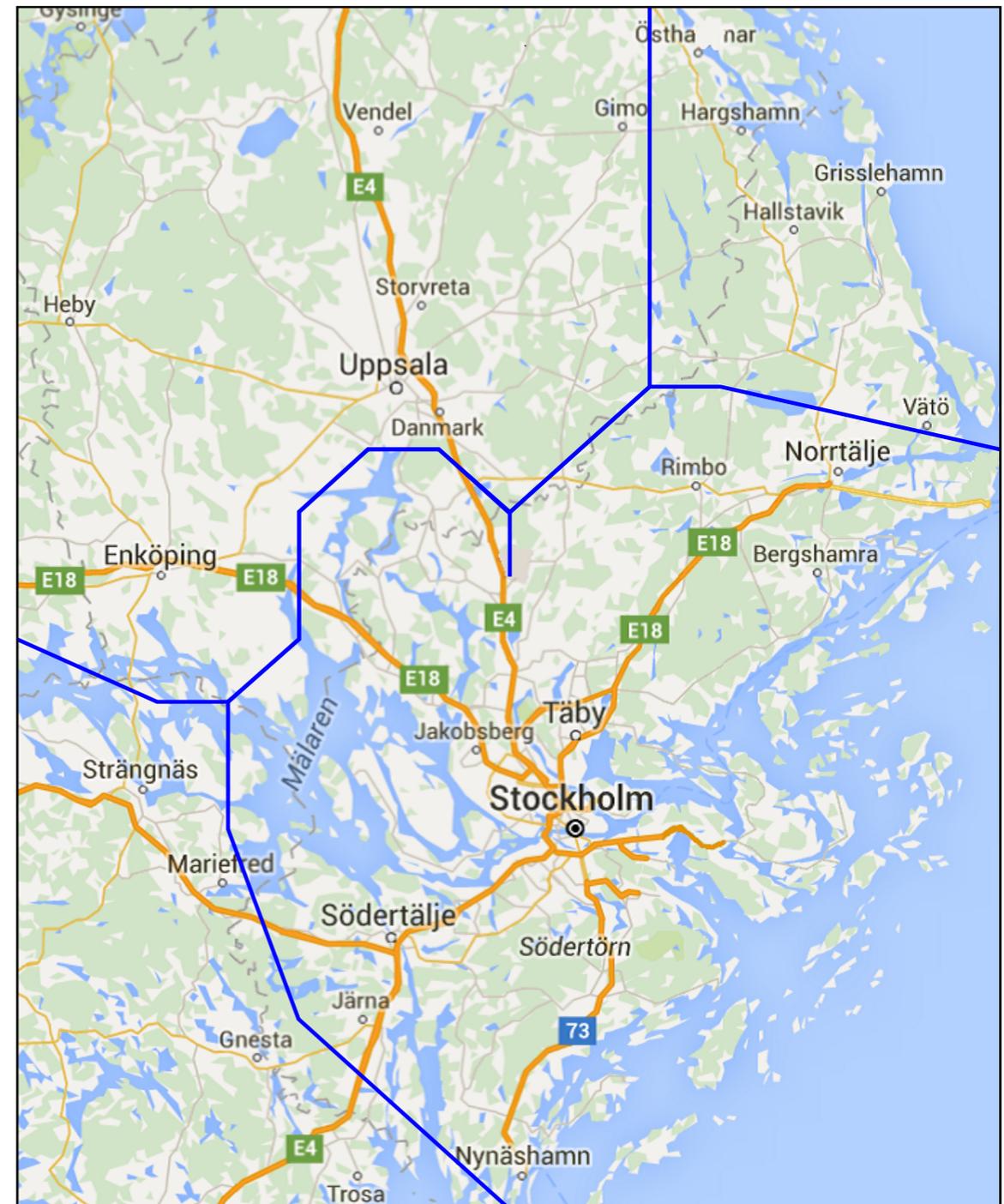
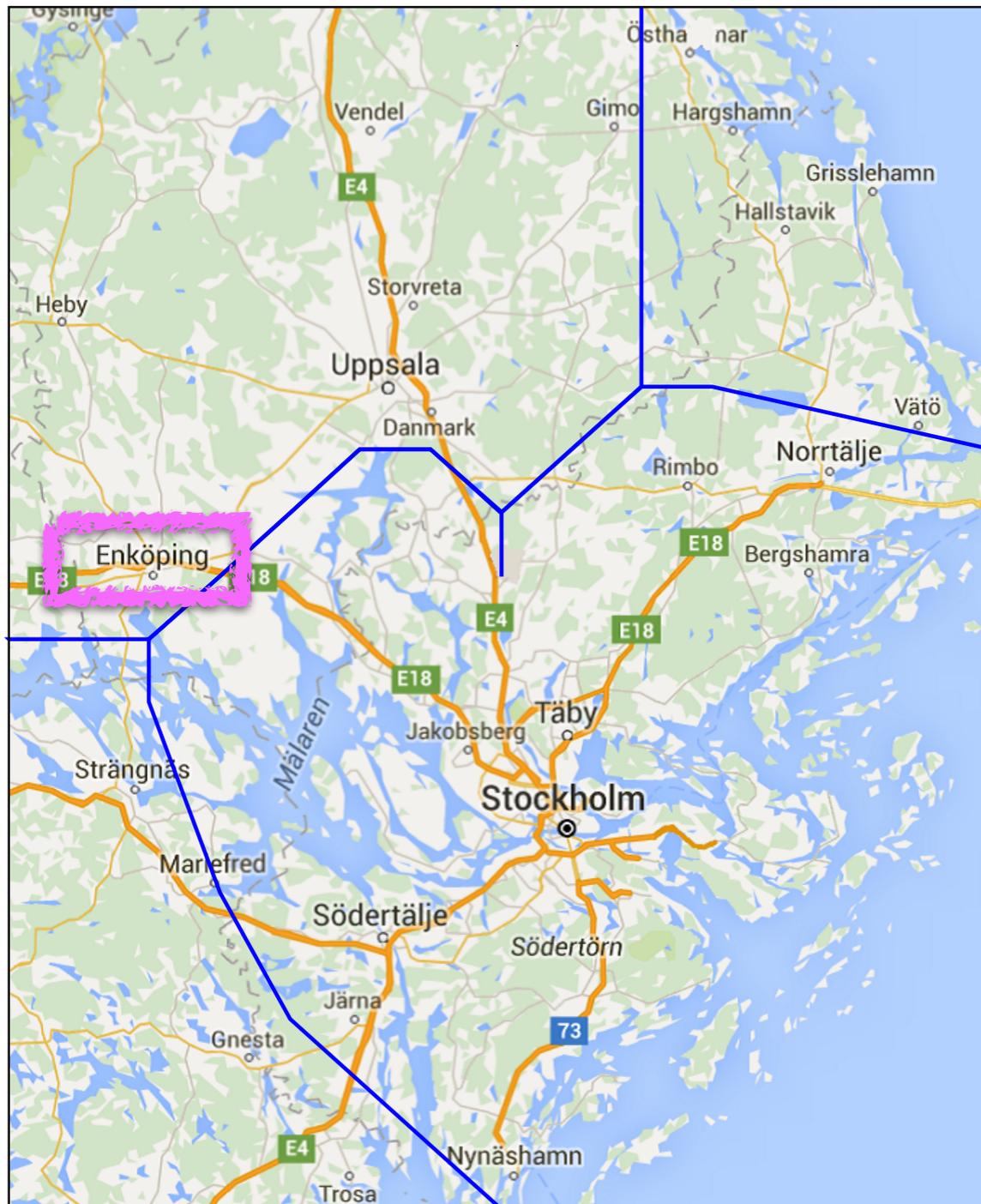
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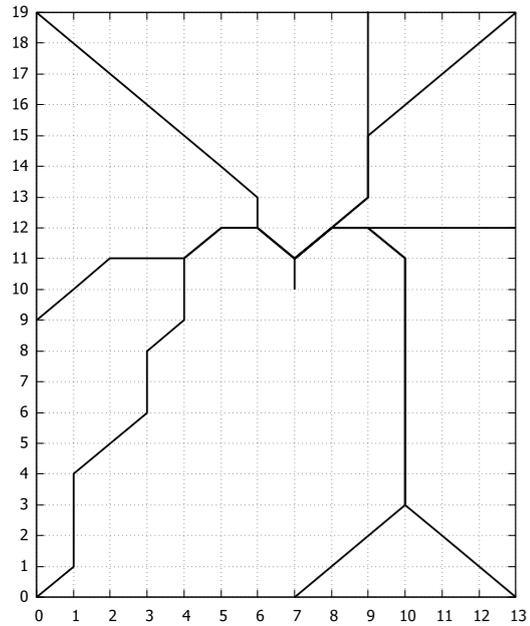
Increased Number of Entry Points:

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paths length

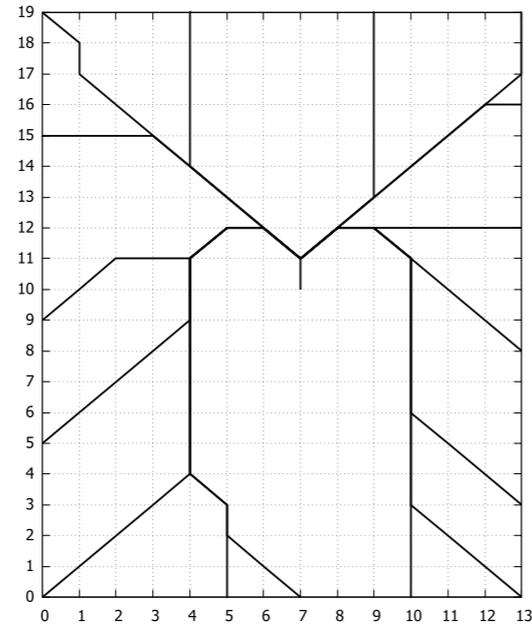
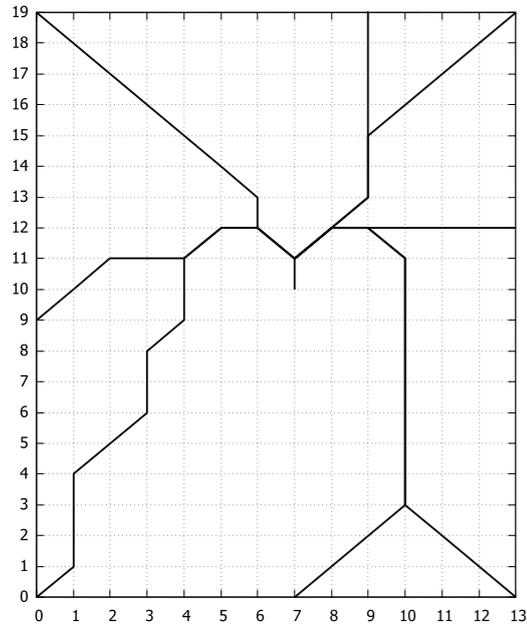
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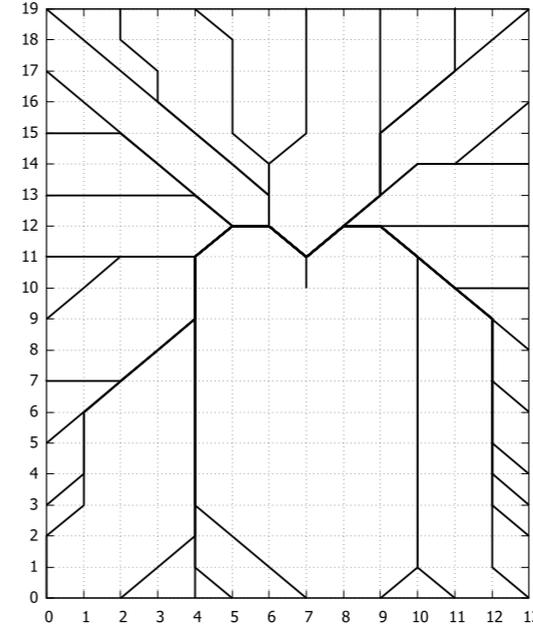
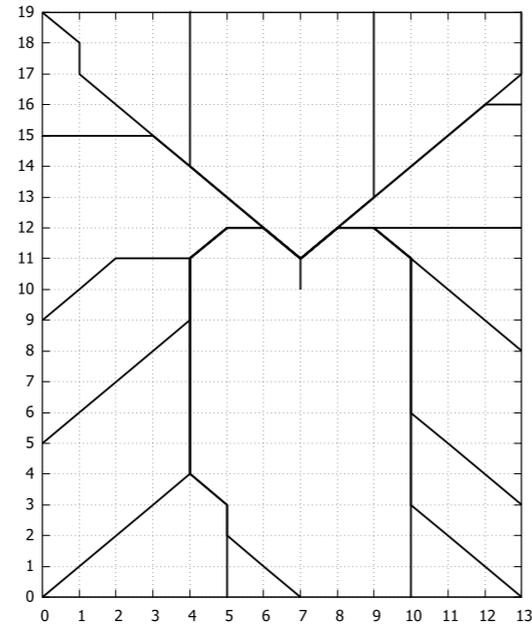
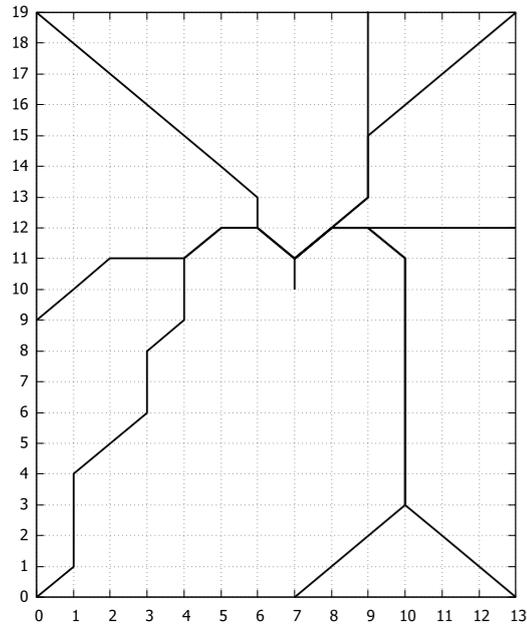
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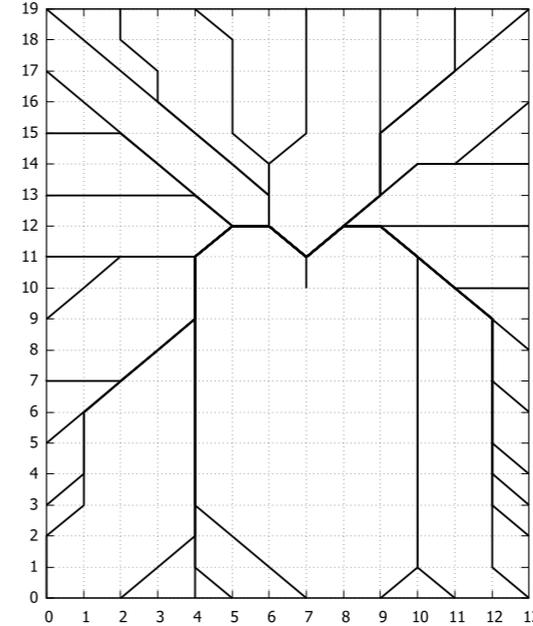
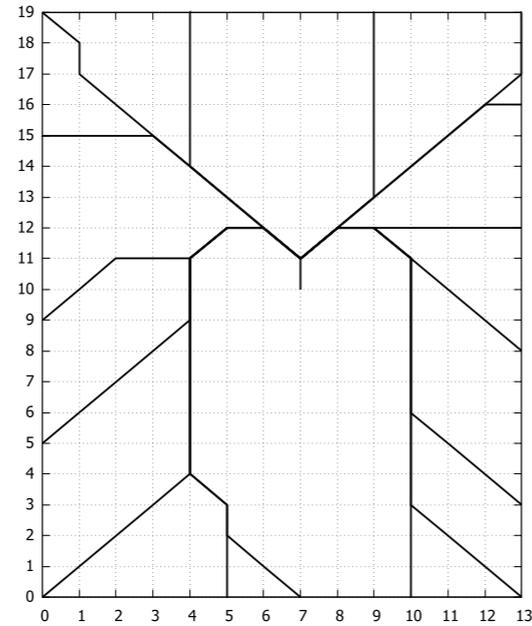
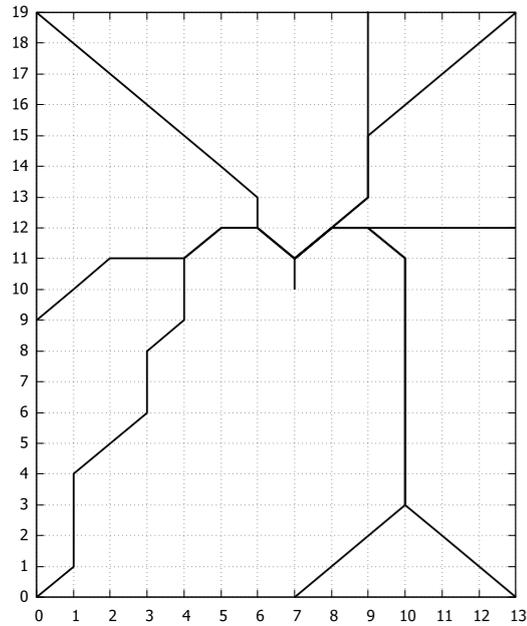
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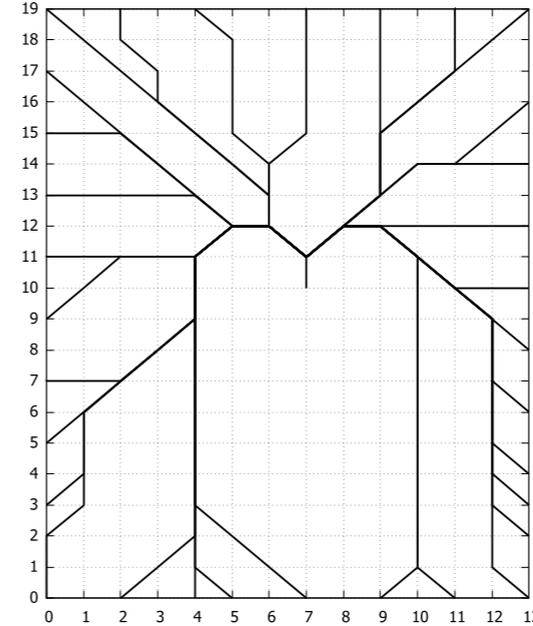
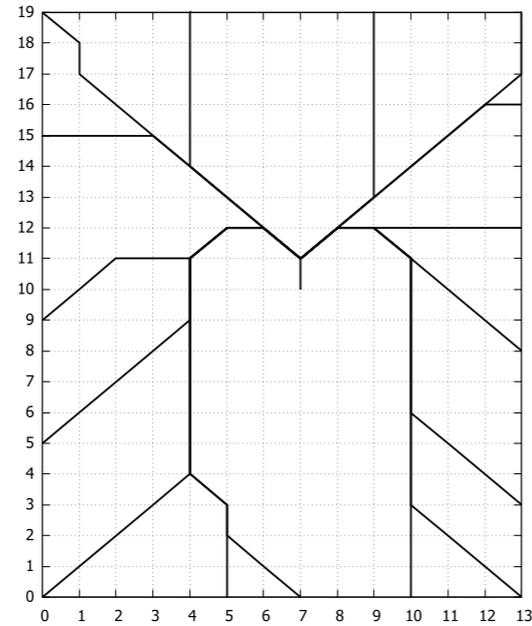
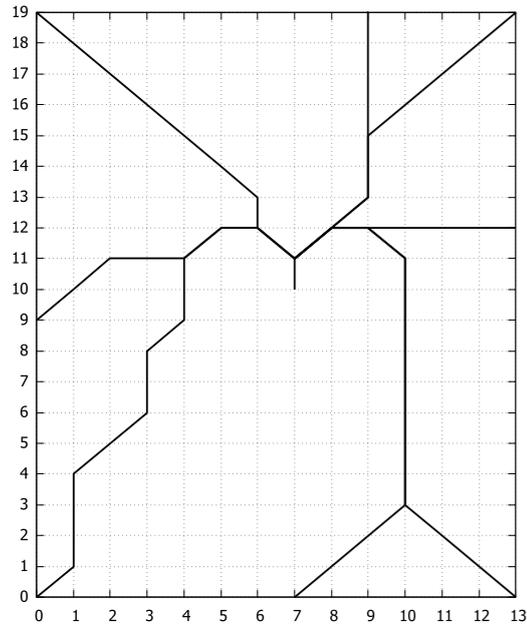
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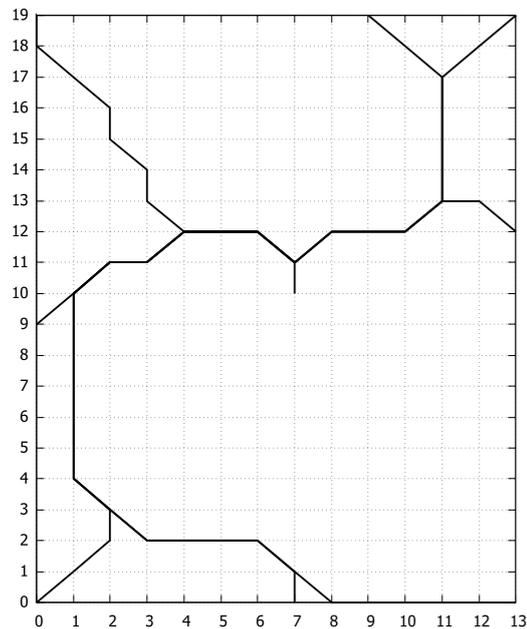
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paths length

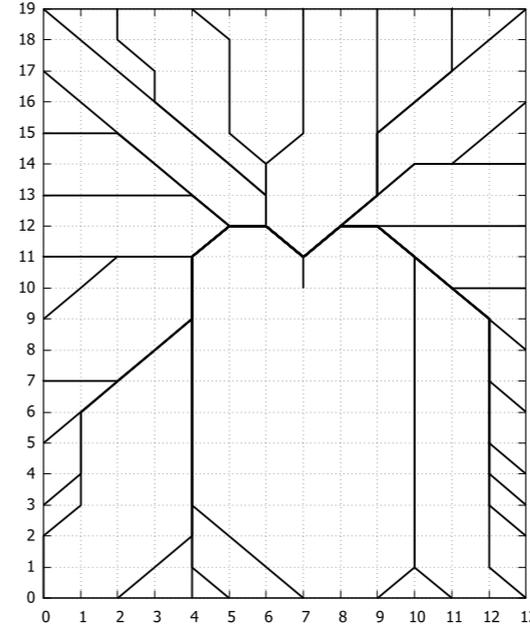
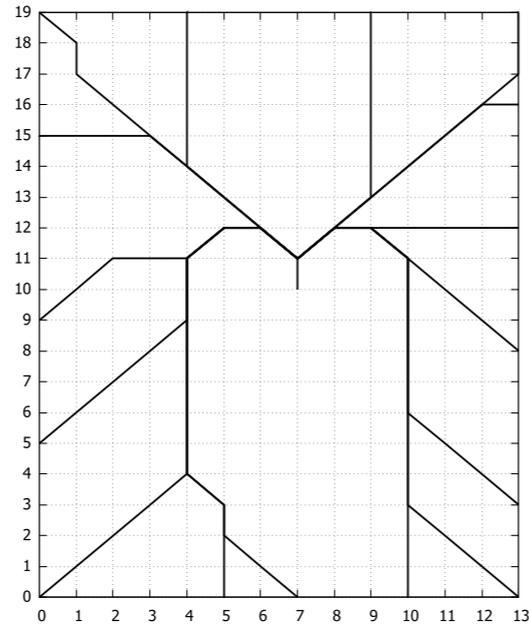
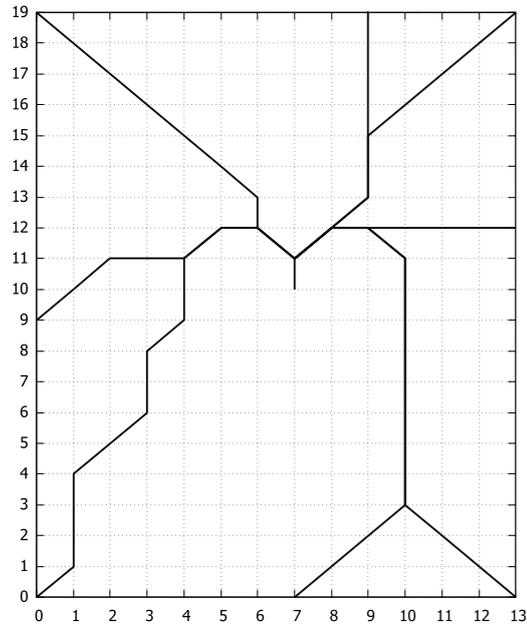


tree weight

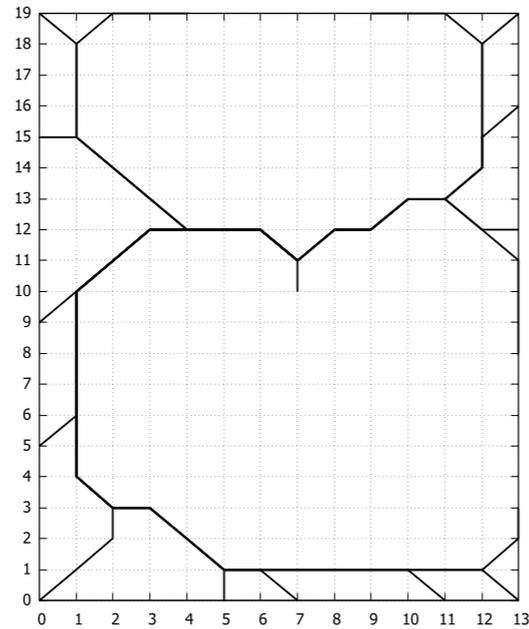
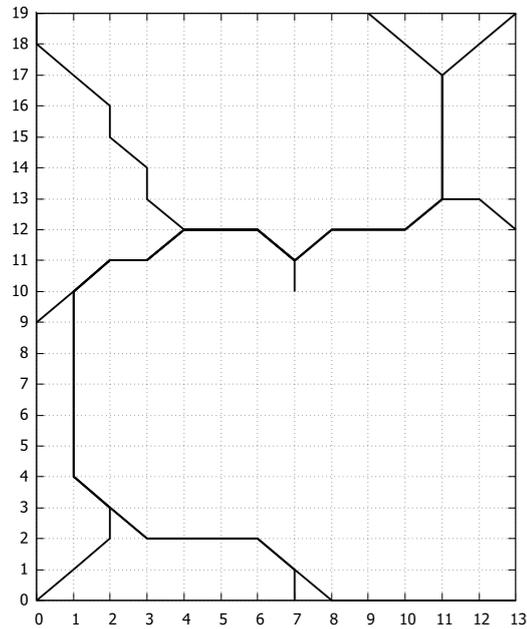


Increased Number of Entry Points:

paths length

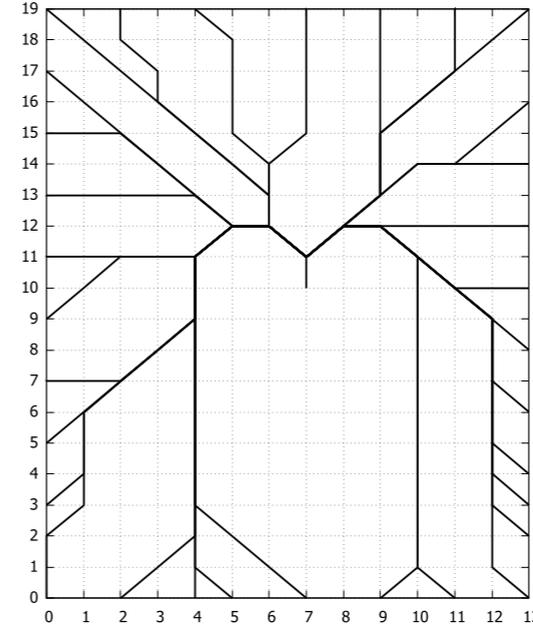
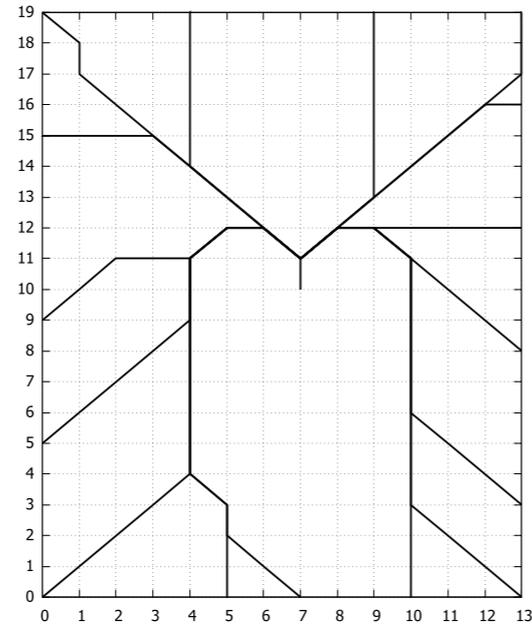
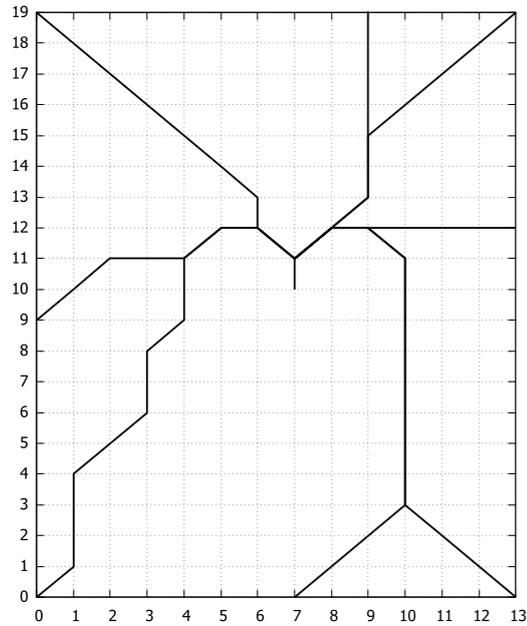


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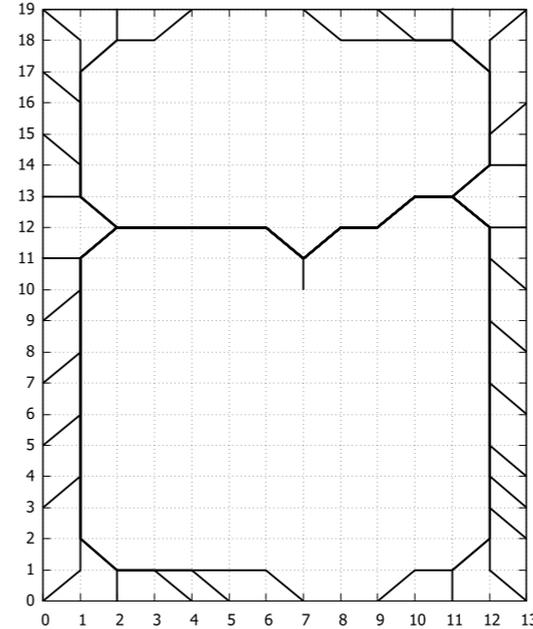
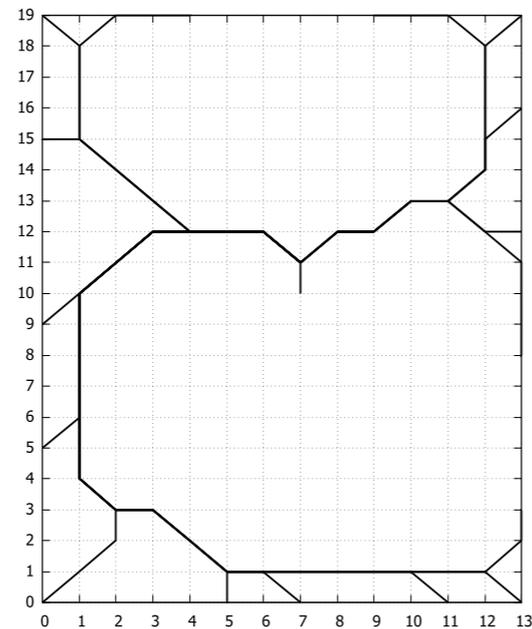
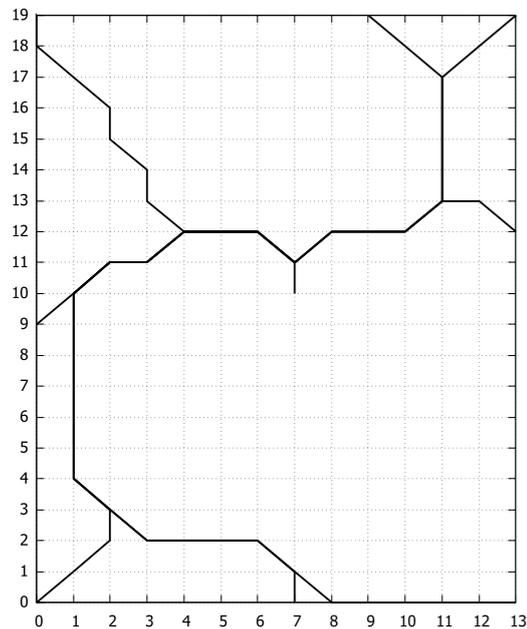


Increased Number of Entry Points:

paths length

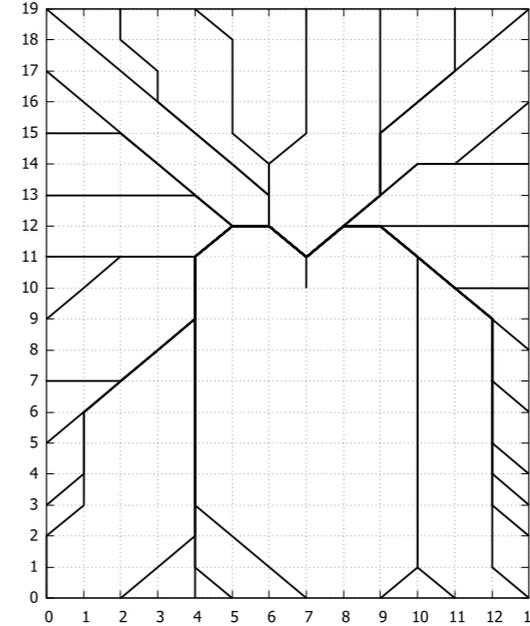
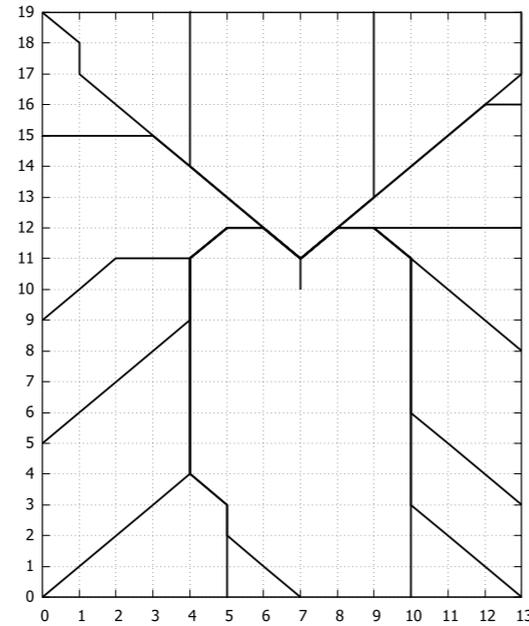
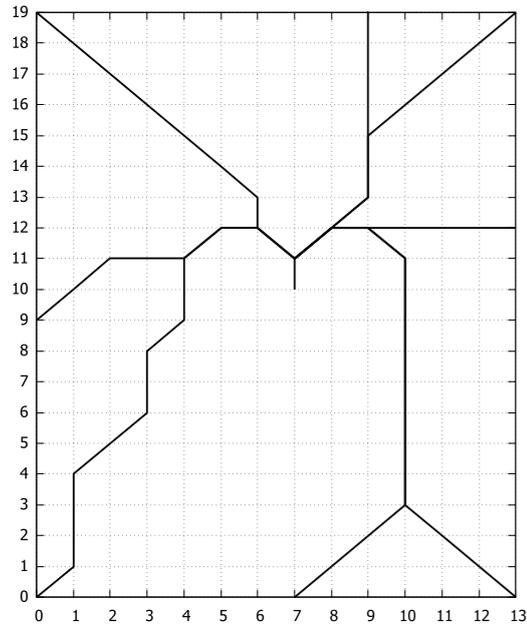


tree weight



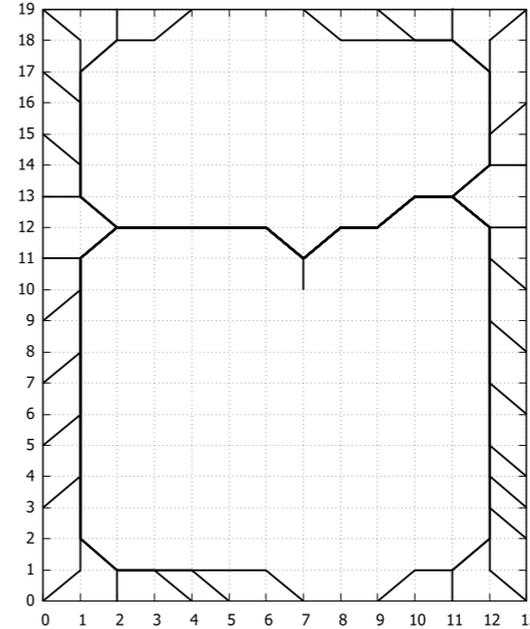
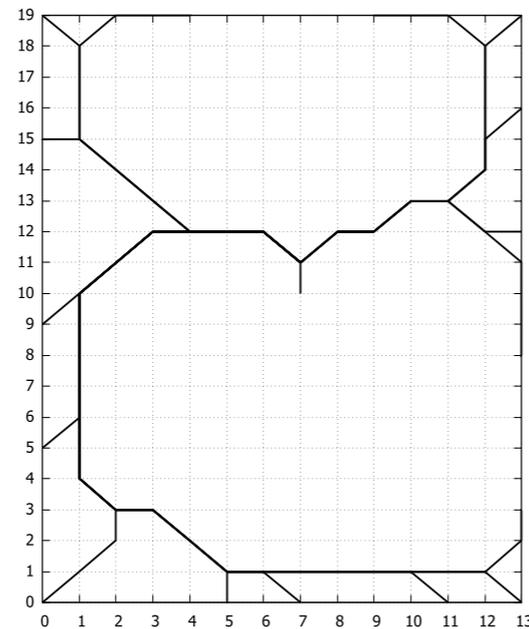
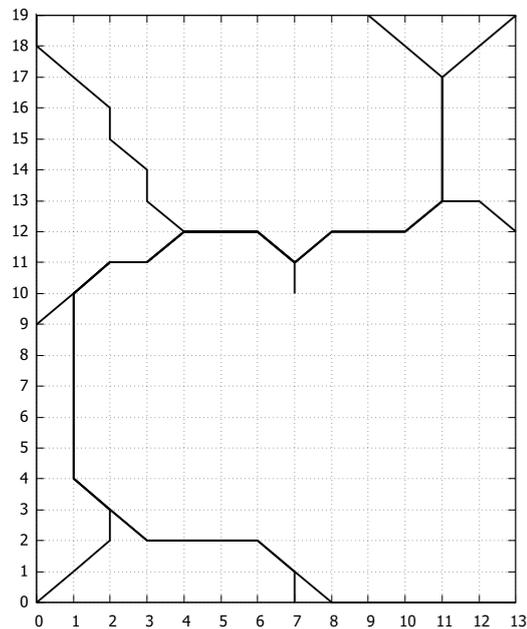
Increased Number of Entry Points:

paths length



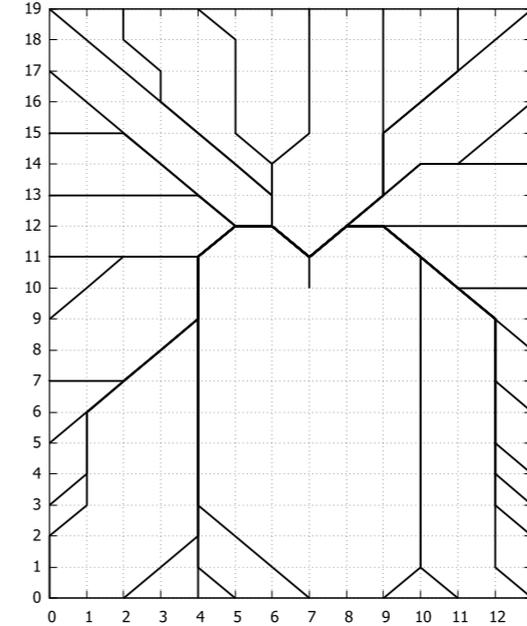
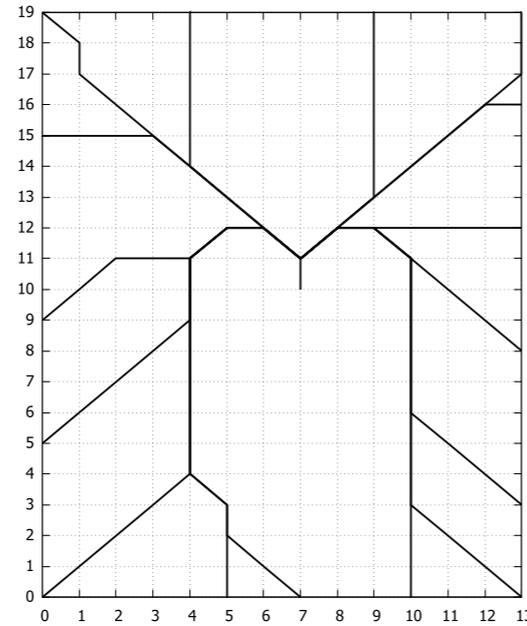
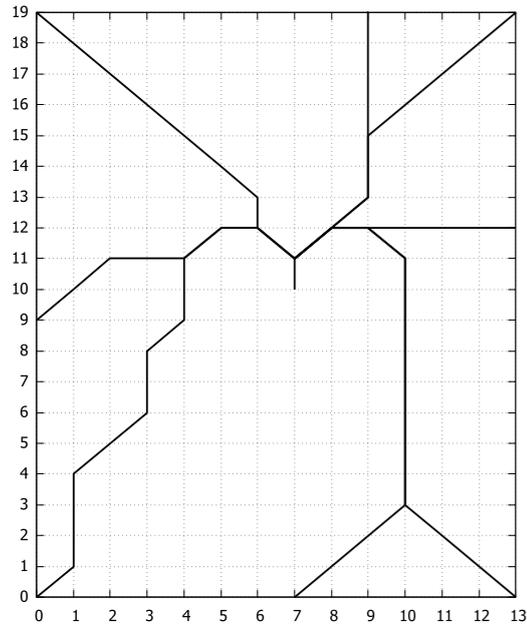
serve the airlines' request for short trajectories best

tree weight



Increased Number of Entry Points:

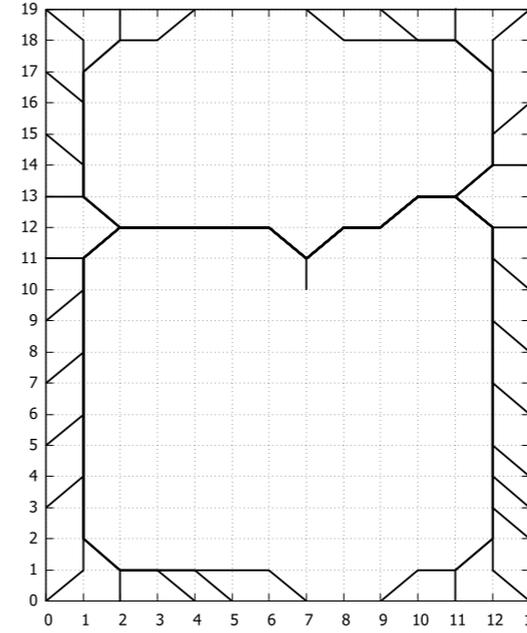
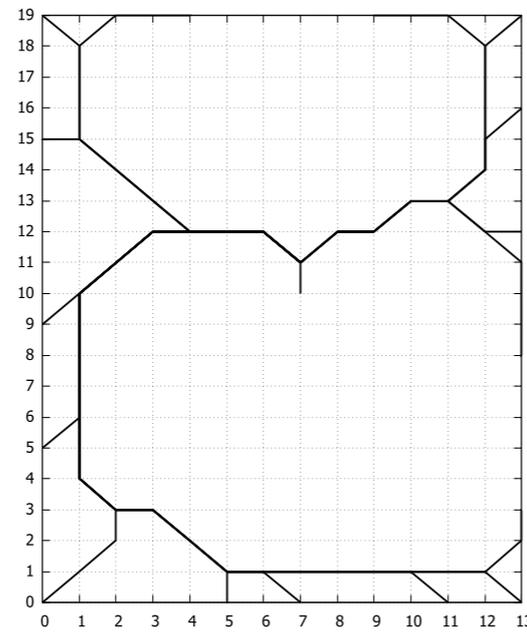
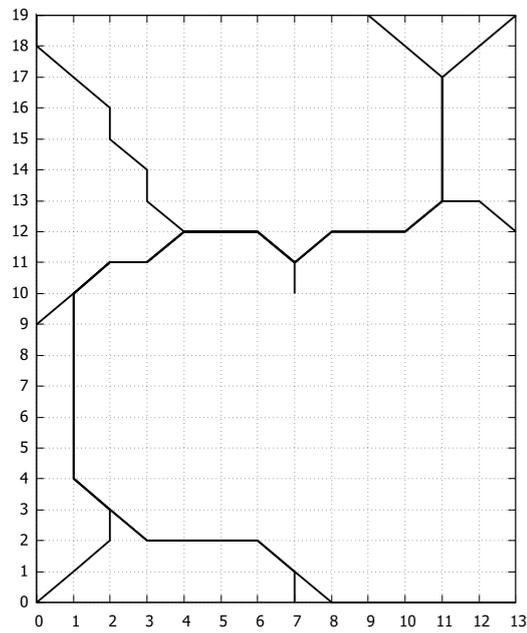
paths length



serve the airlines' request for short trajectories best

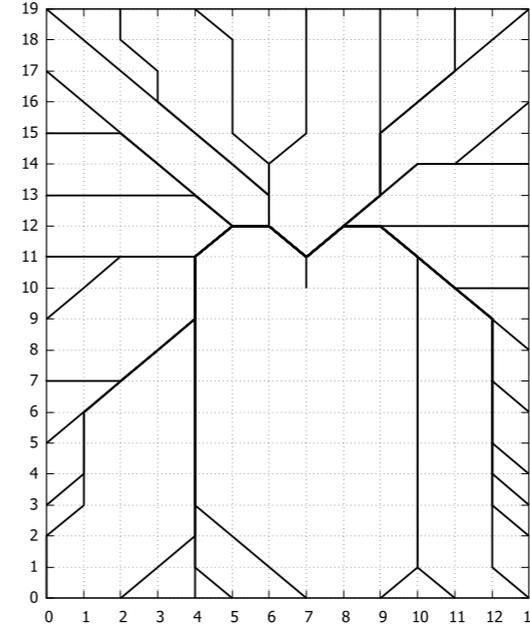
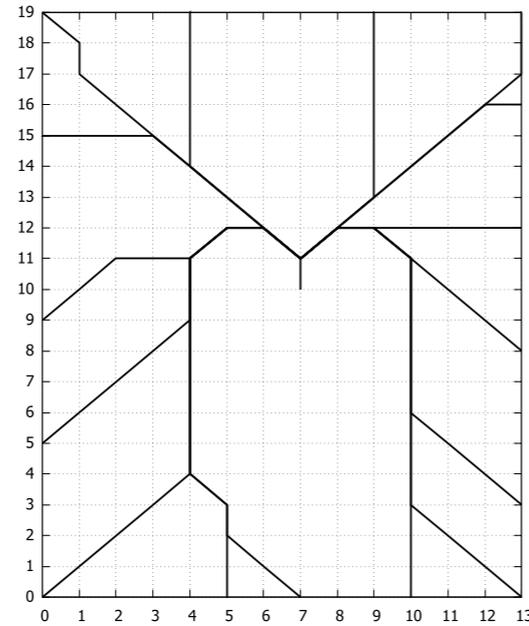
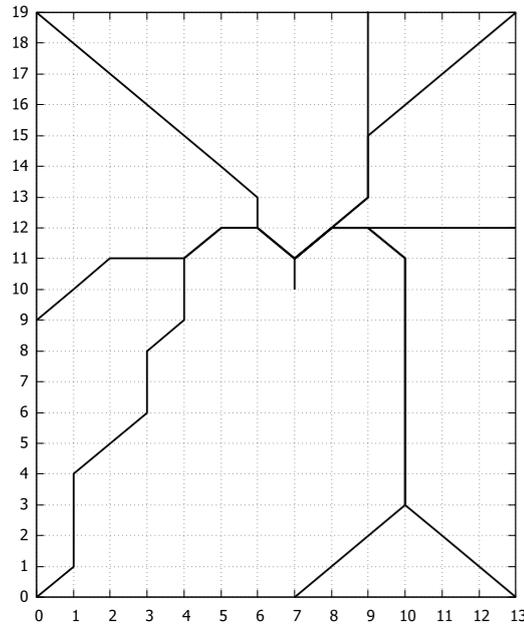
quite dense network of routes →

tree weight



Increased Number of Entry Points:

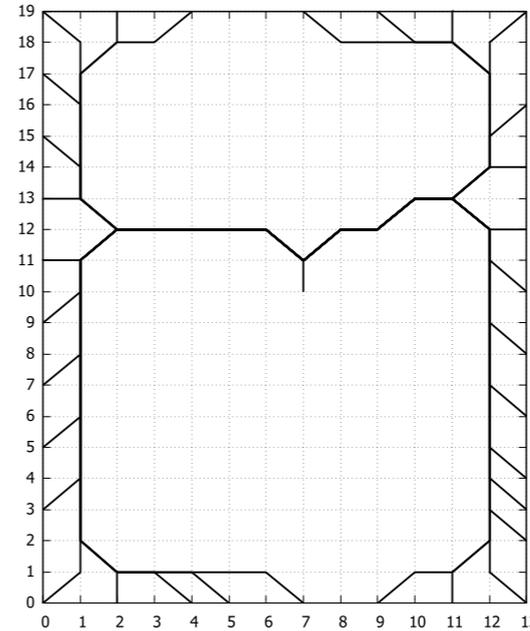
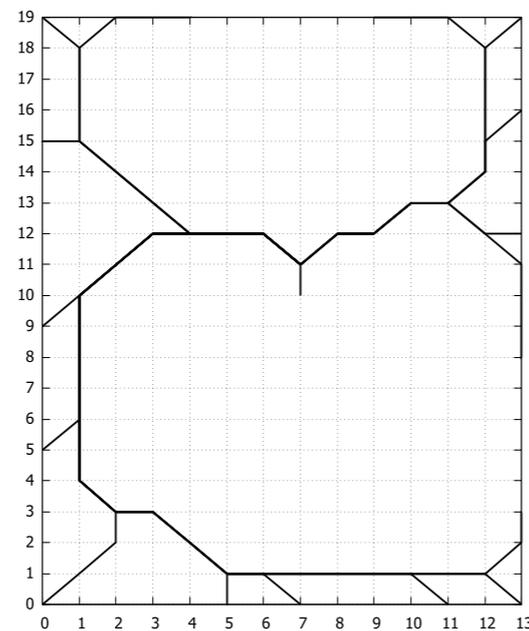
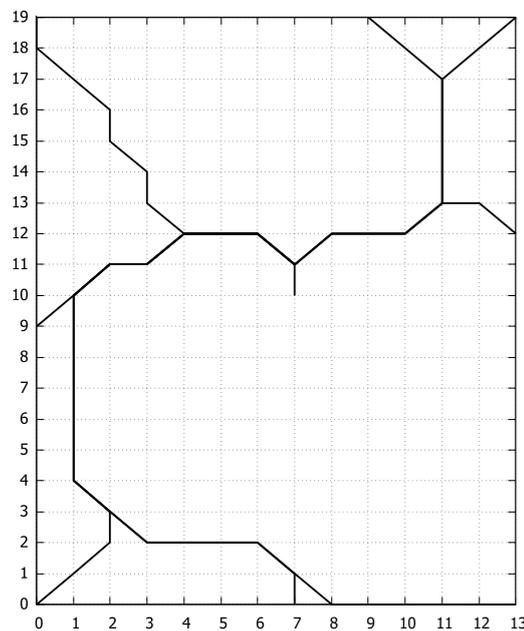
paths length



serve the airlines' request for short trajectories best

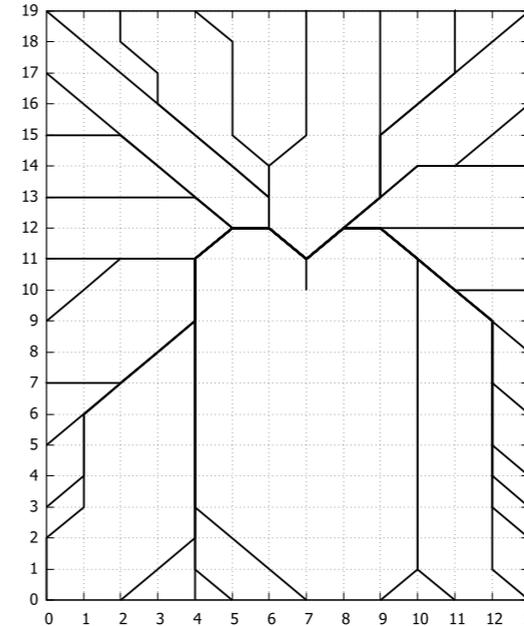
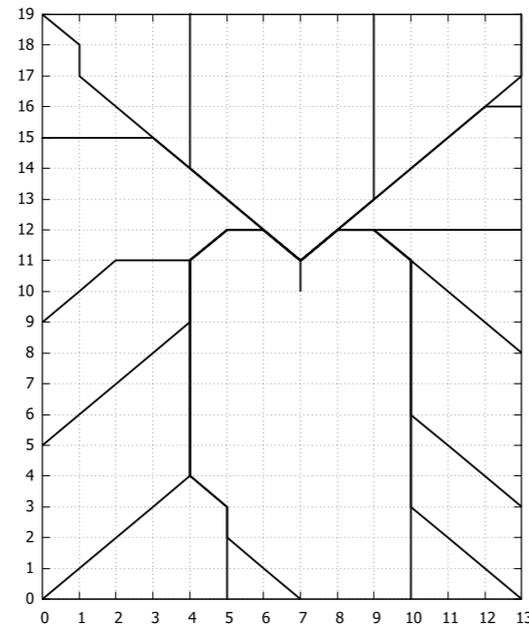
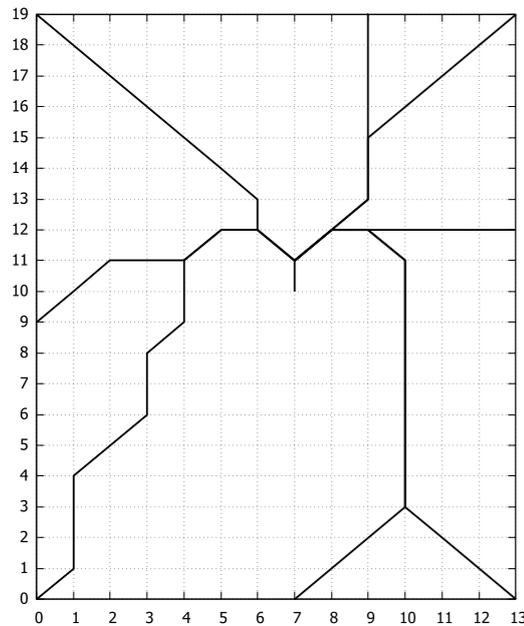
quite dense network of routes → hard to control the traffic

tree weight



Increased Number of Entry Points:

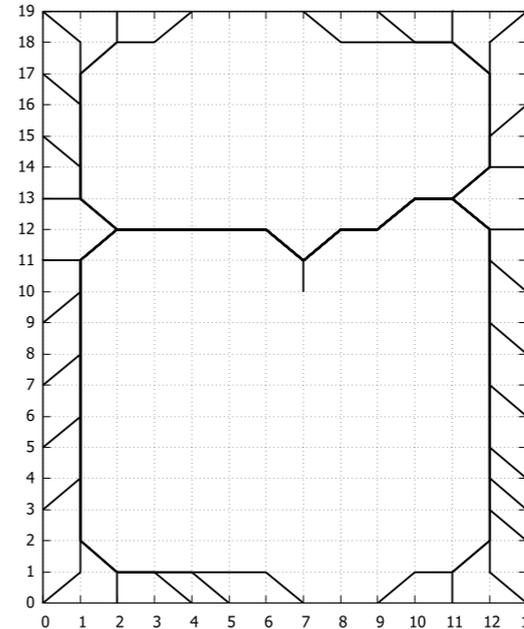
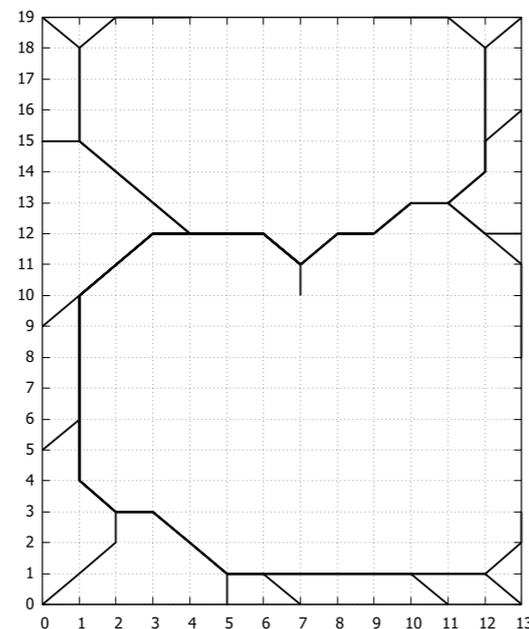
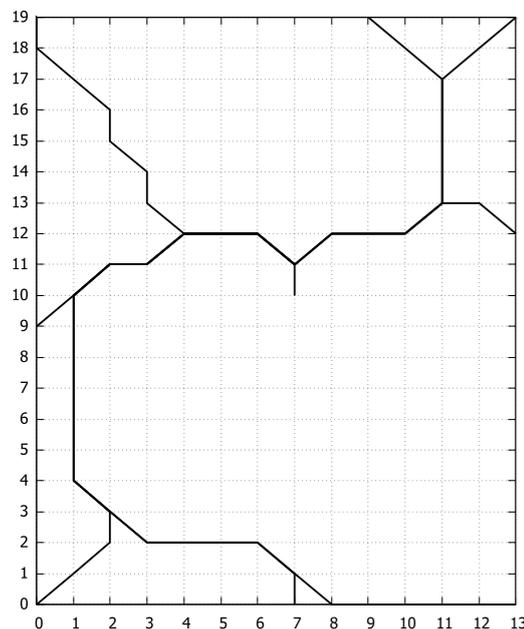
paths length



serve the airlines' request for short trajectories best

quite dense network of routes → hard to control the traffic

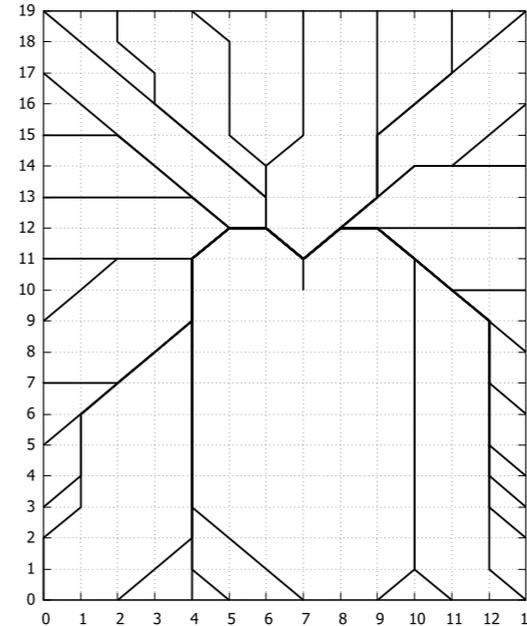
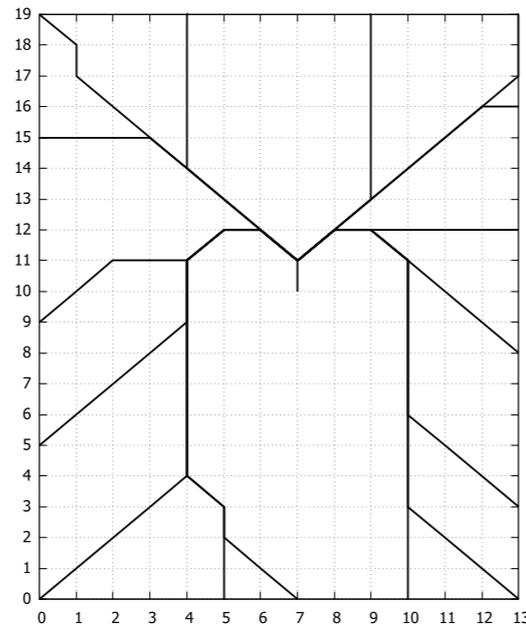
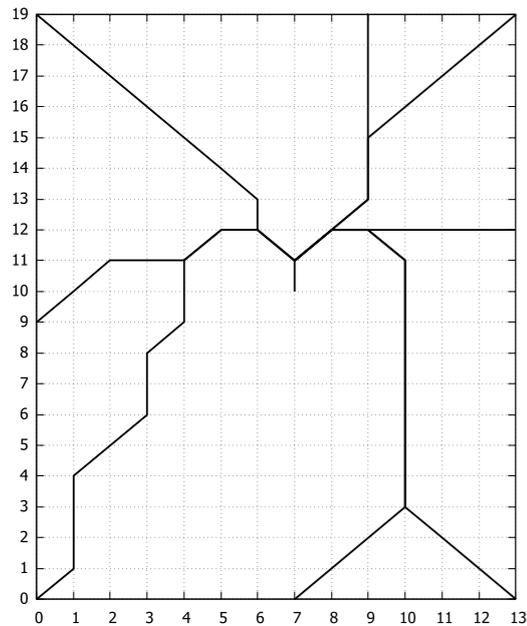
tree weight



most merge points are located close to TMA boundary

Increased Number of Entry Points:

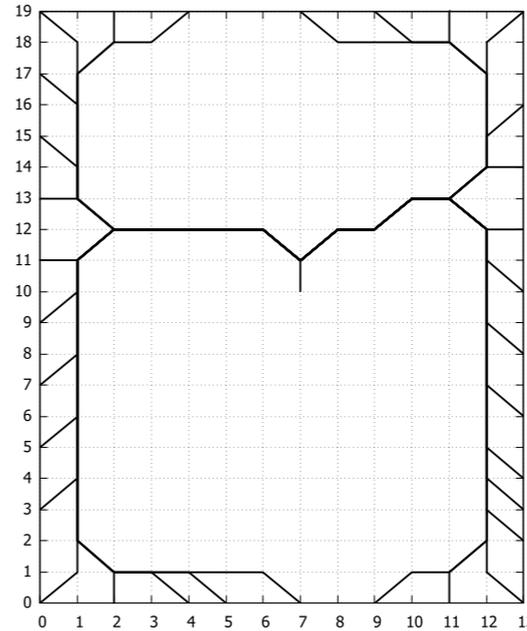
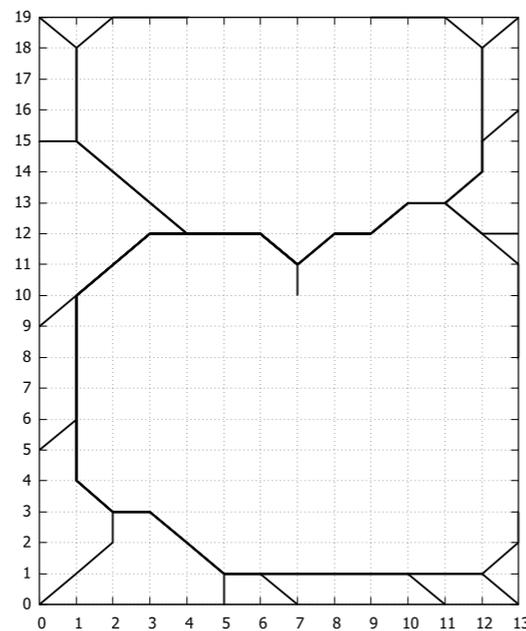
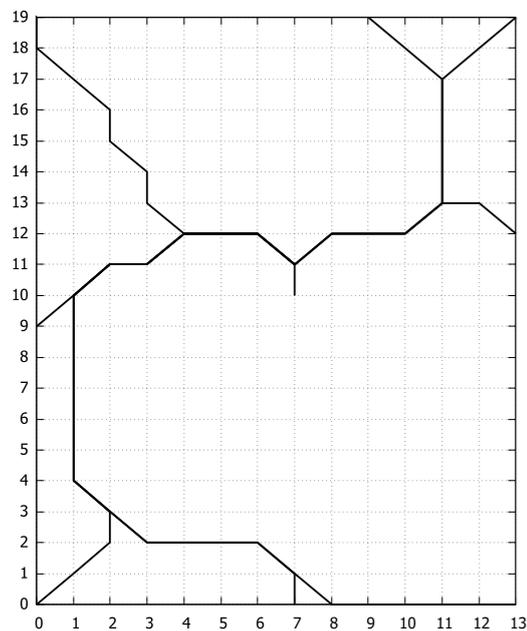
paths length



serve the airlines' request for short trajectories best

quite dense network of routes → hard to control the traffic

tree weight

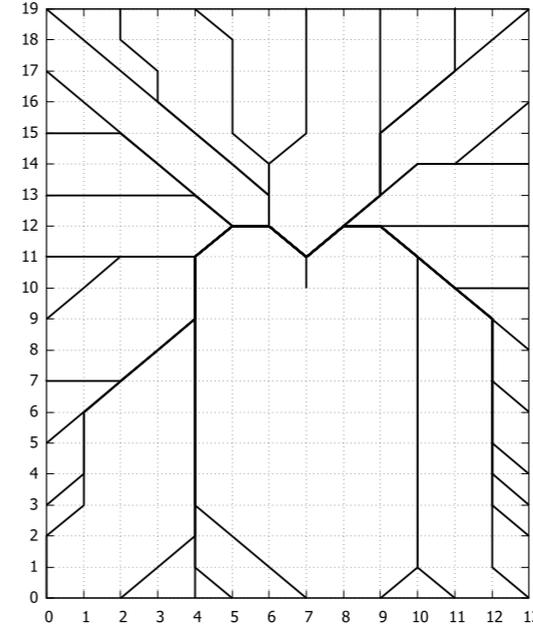
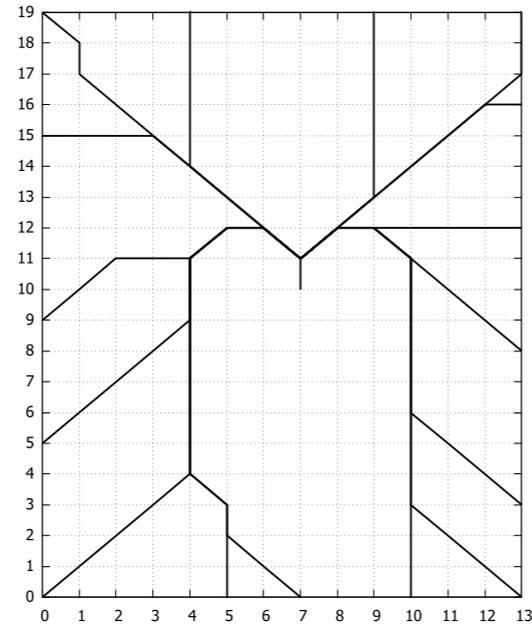
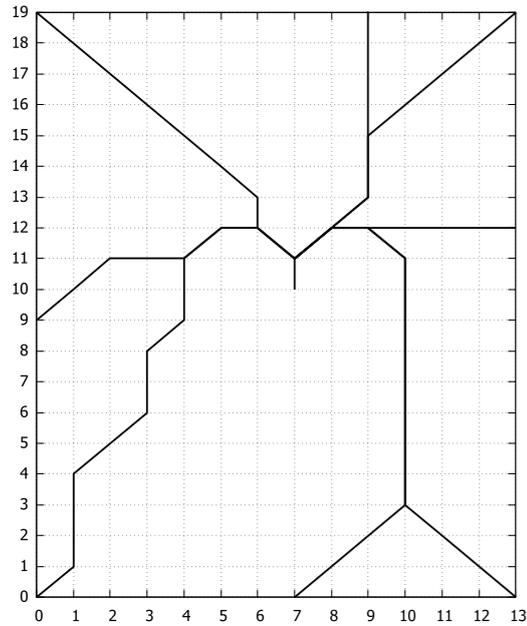


most merge points are located close to TMA boundary

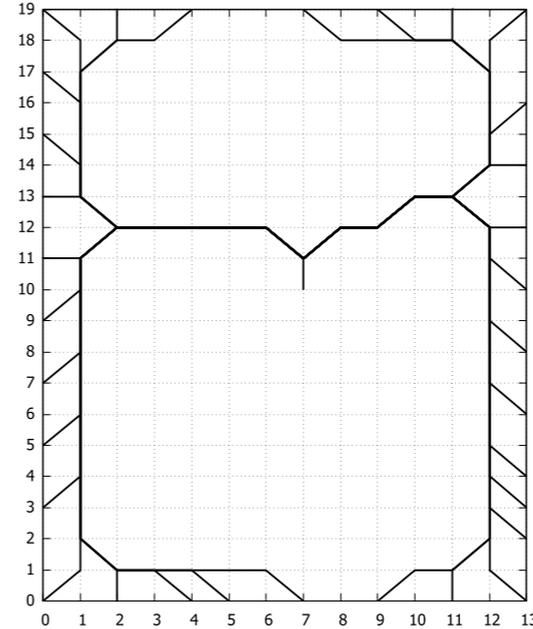
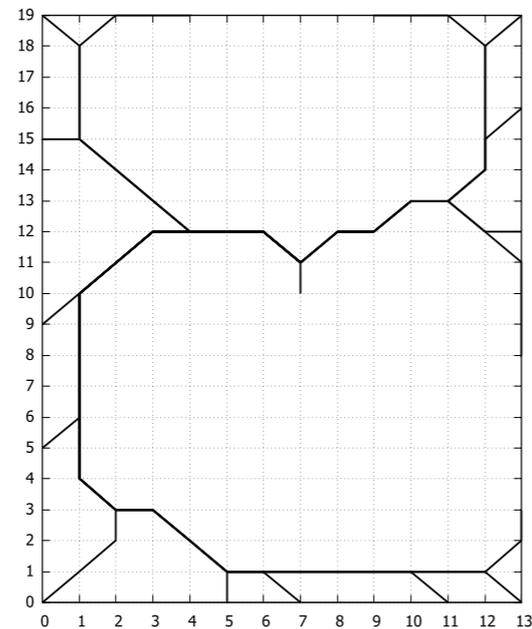
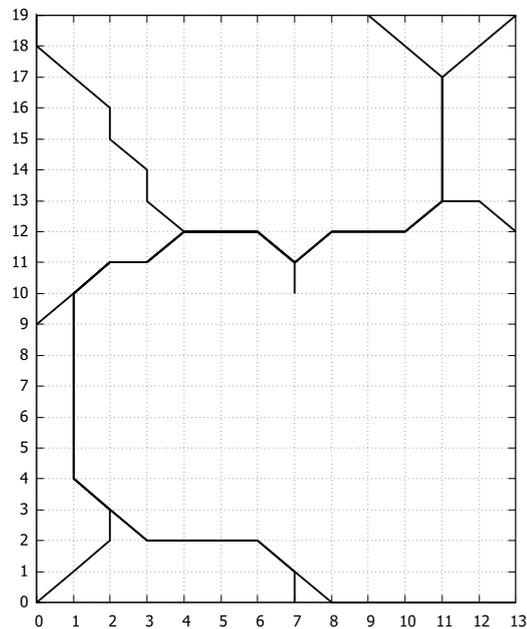
→ helpful to use linear combination of these two functions

Increased Number of Entry Points:

paths length



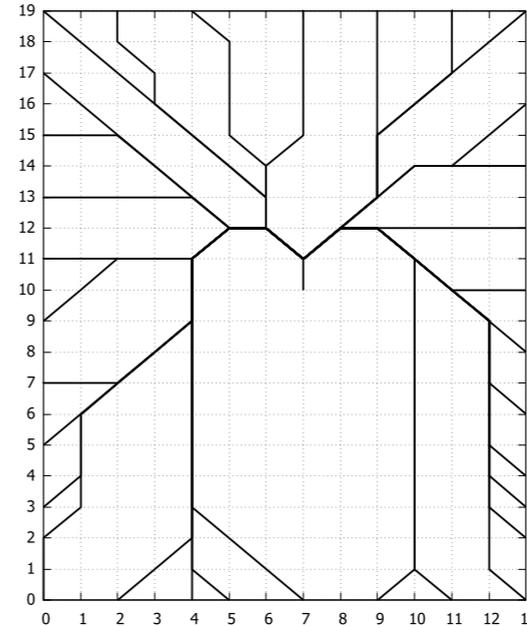
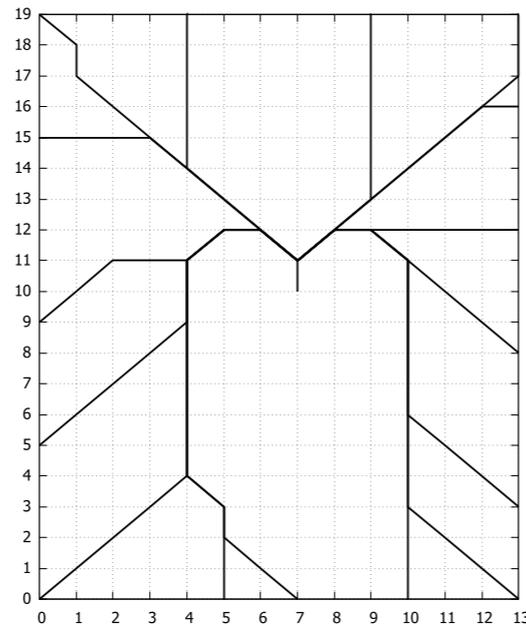
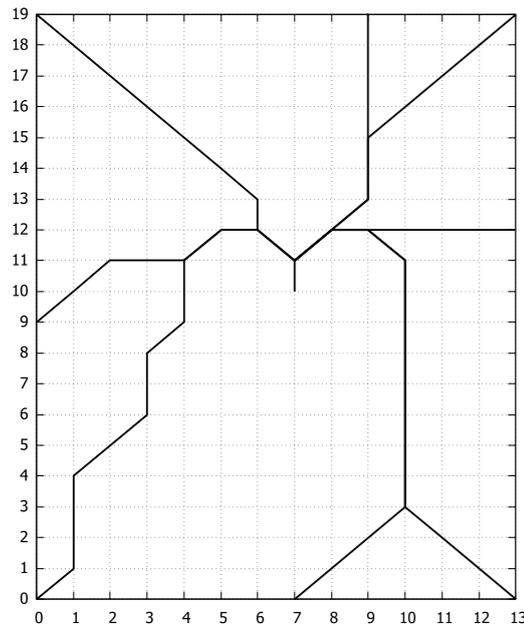
tree weight



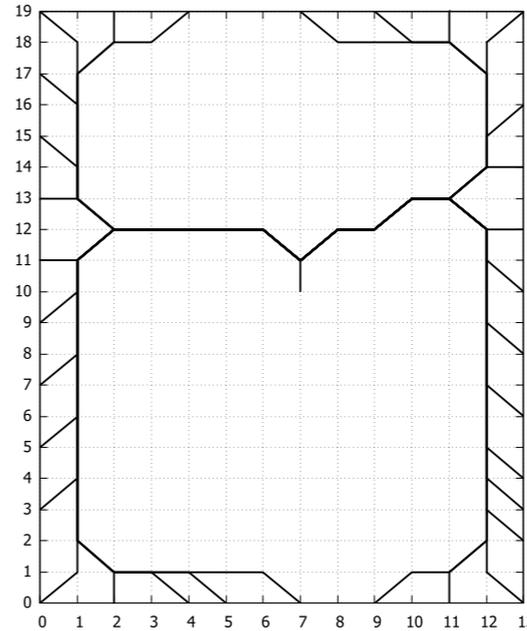
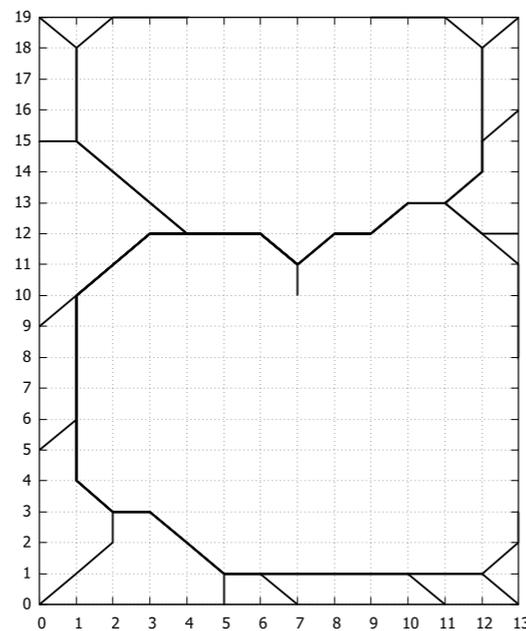
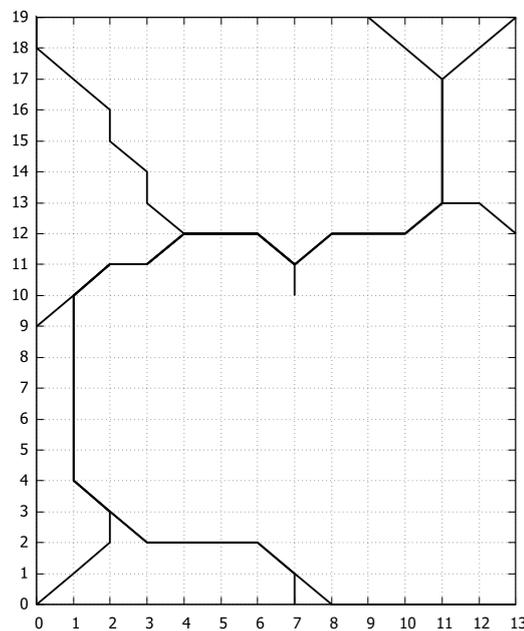
→ helpful to use linear combination of these two functions

Increased Number of Entry Points:

paths length



tree weight

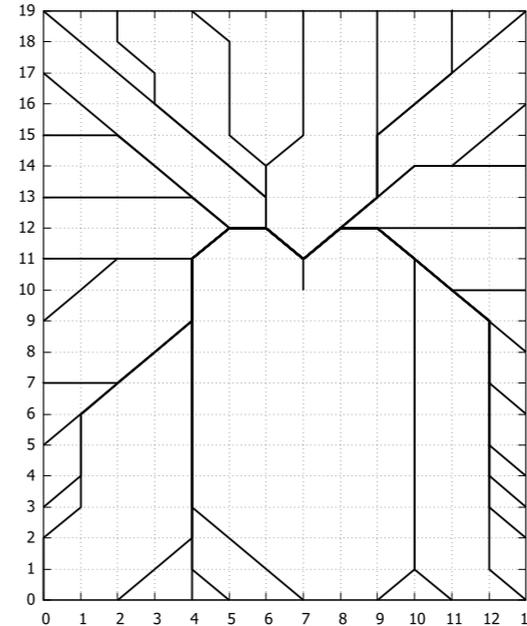
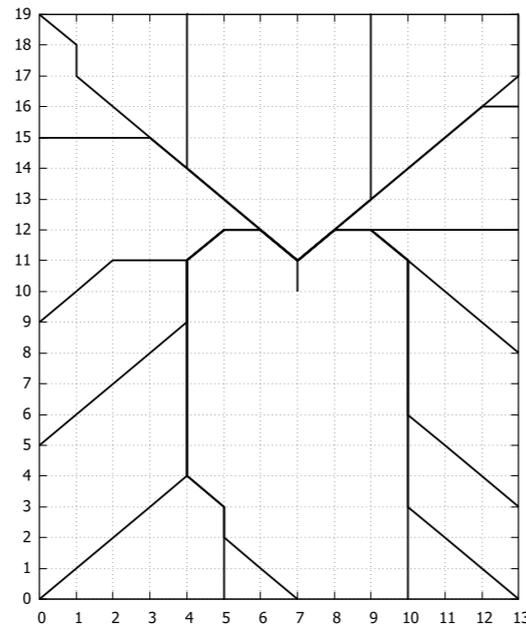
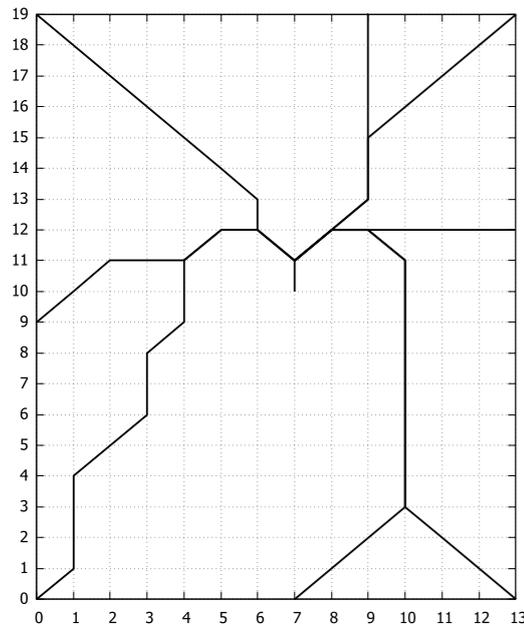


Solutions for large number of entry points could be used to suggest the number and location of entry points for a design from scratch.

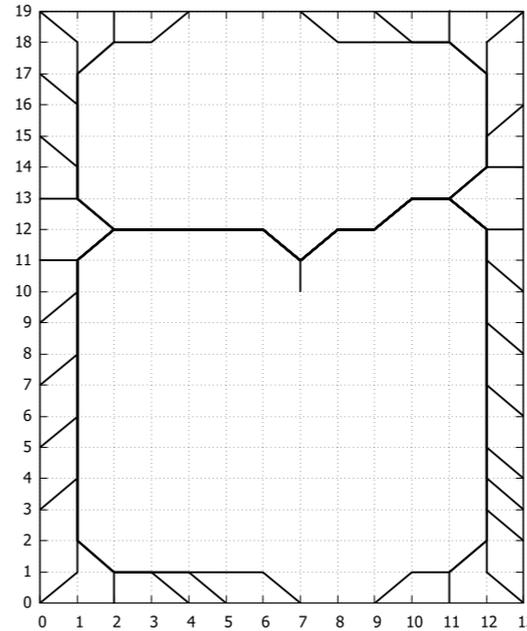
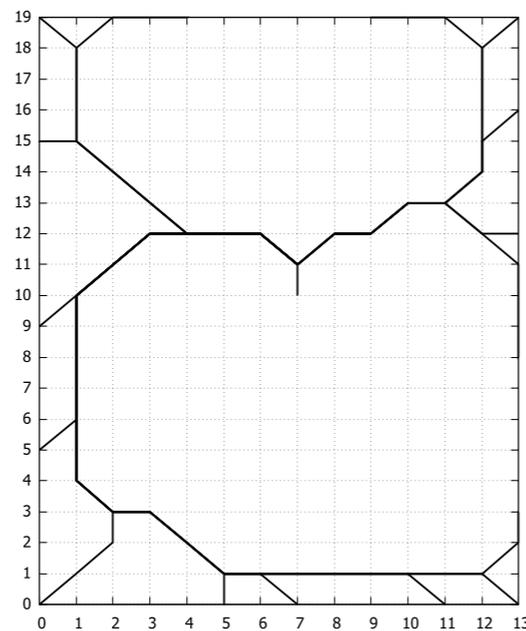
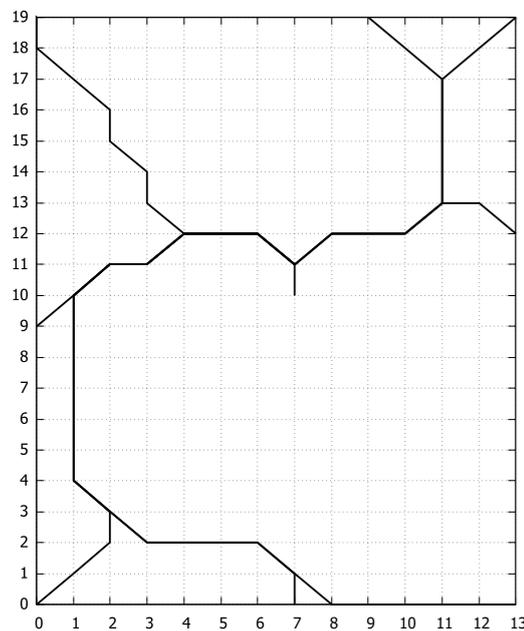
→ helpful to use linear combination of these two functions

Increased Number of Entry Points:

paths length



tree weight



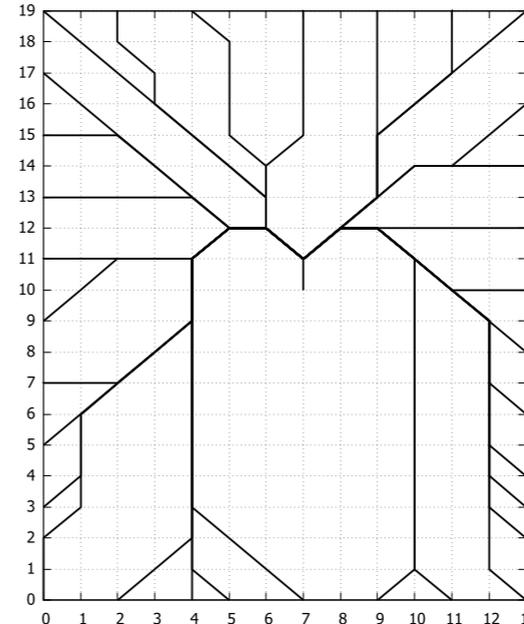
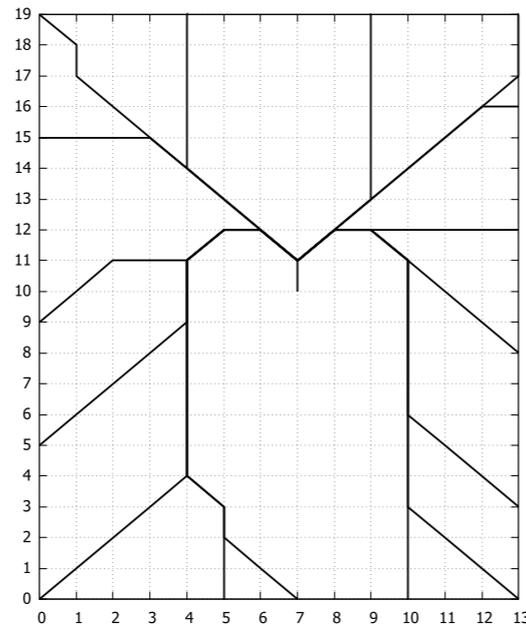
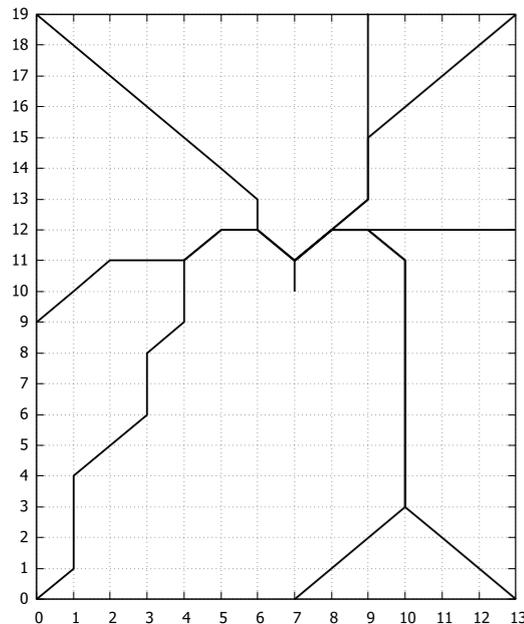
Solutions for large number of entry points could be used to suggest the number and location of entry points for a design from scratch.

2 entry points

→ helpful to use linear combination of these two functions

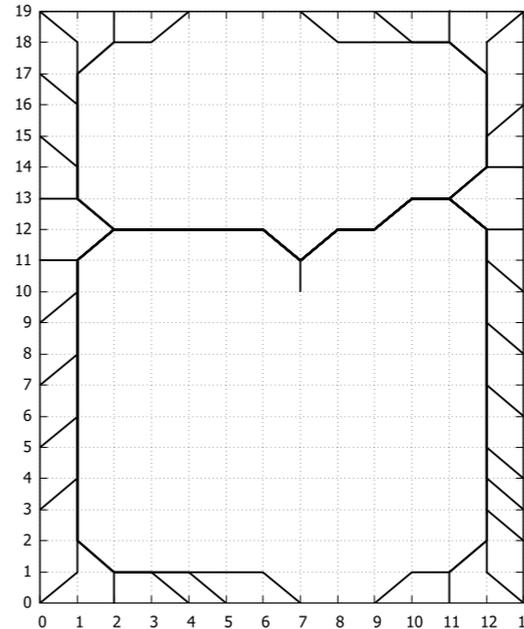
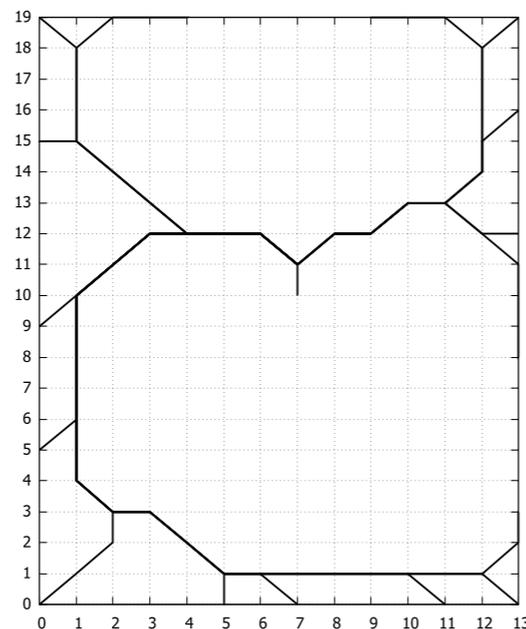
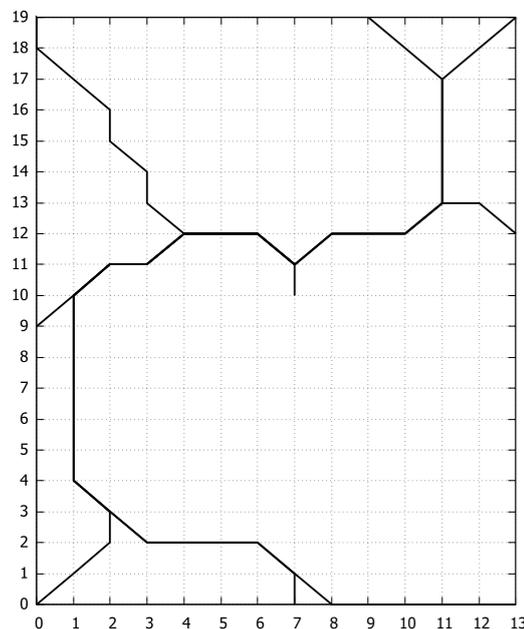
Increased Number of Entry Points:

paths length



16 entry points

tree weight

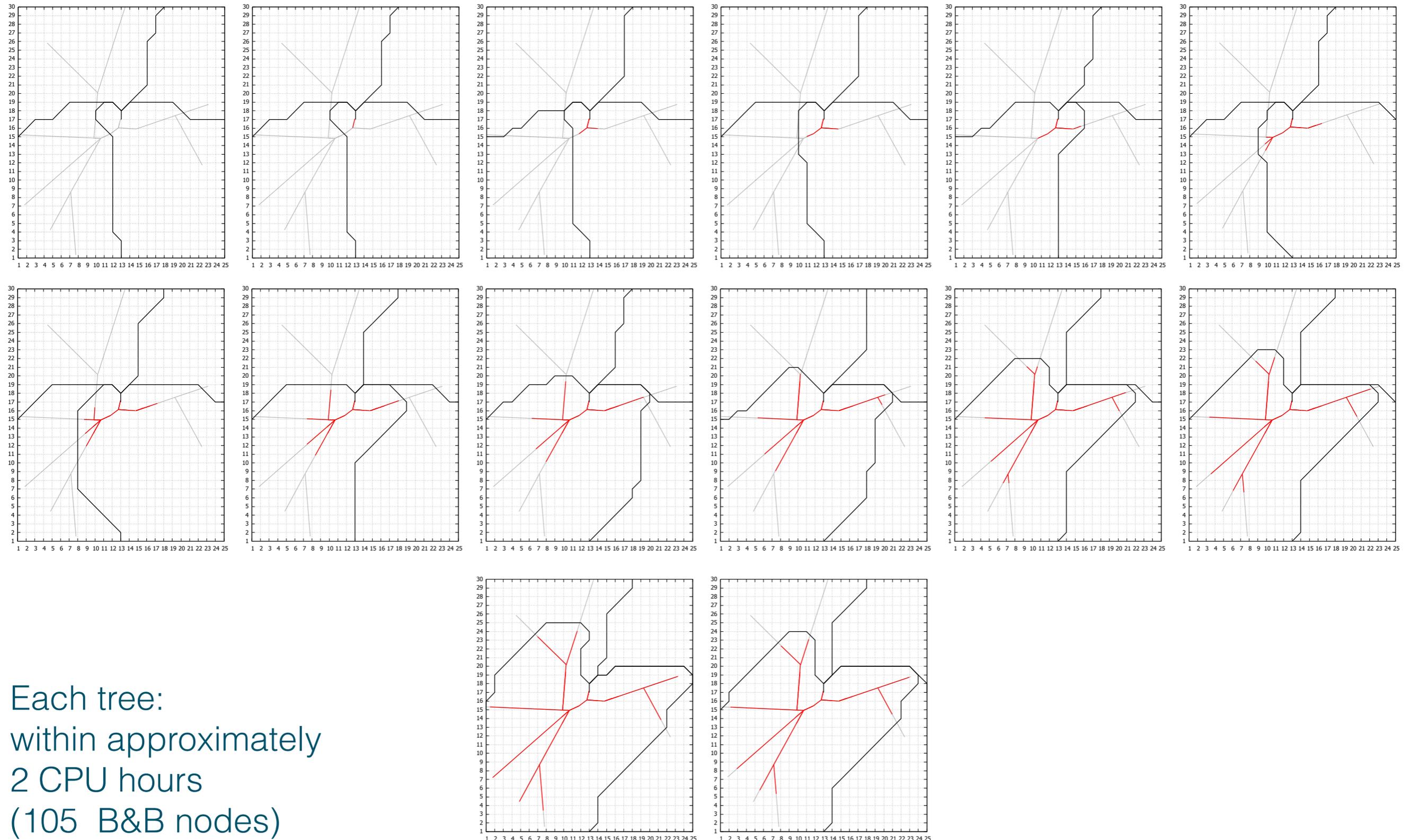


Solutions for large number of entry points could be used to suggest the number and location of entry points for a design from scratch.

2 entry points

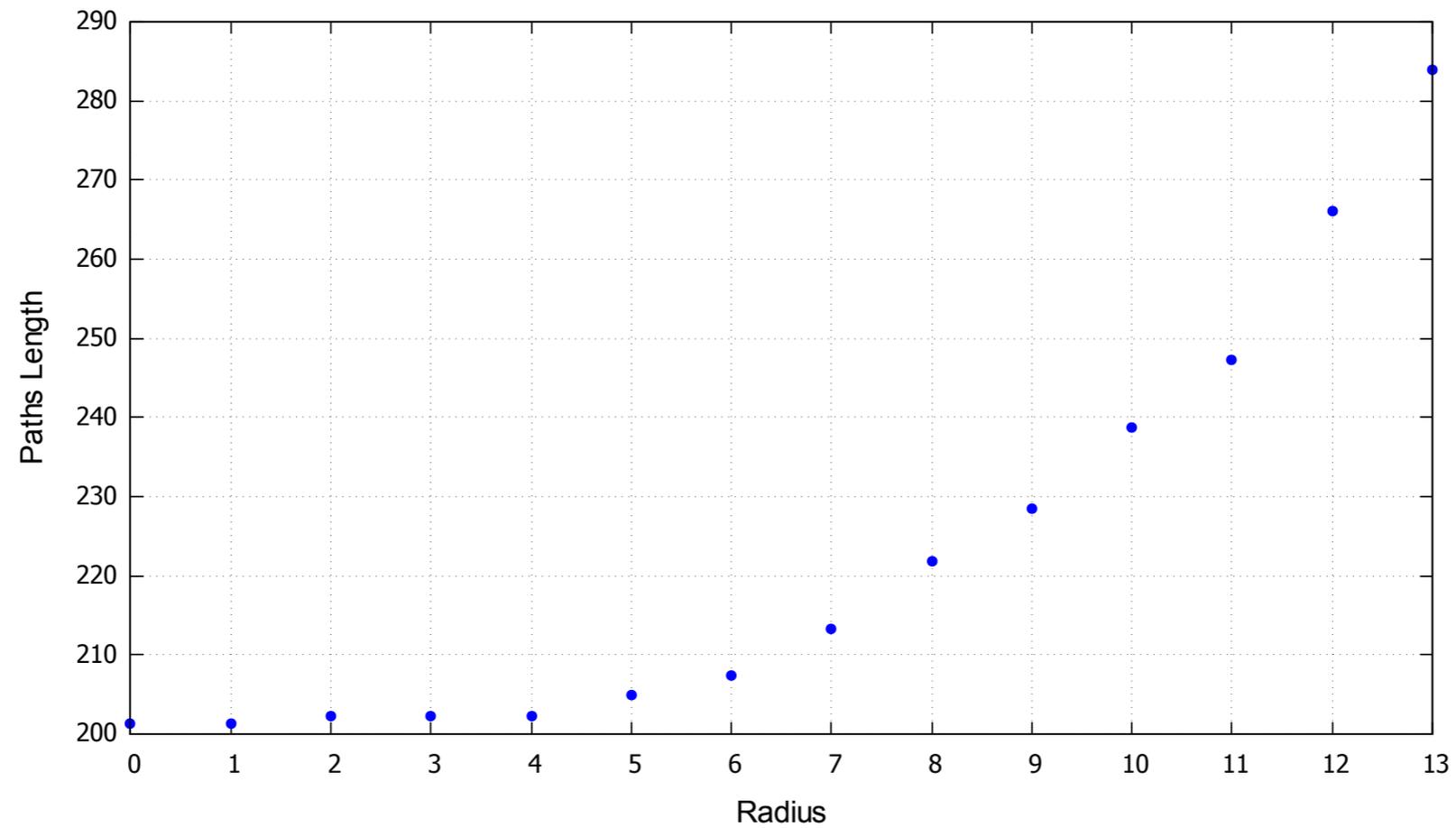
→ helpful to use linear combination of these two functions

SID constraints:

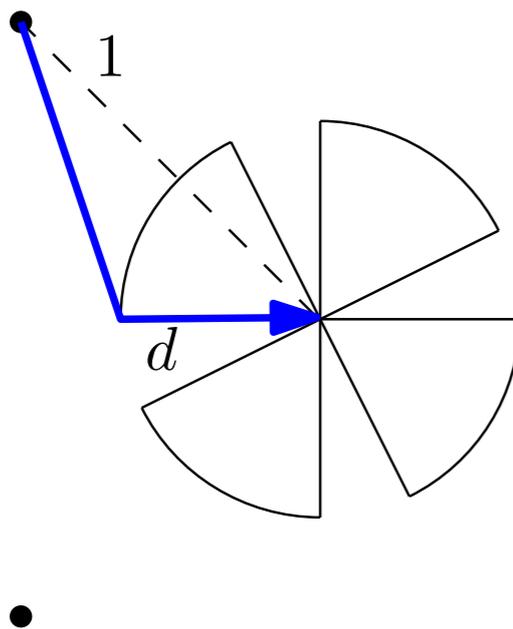
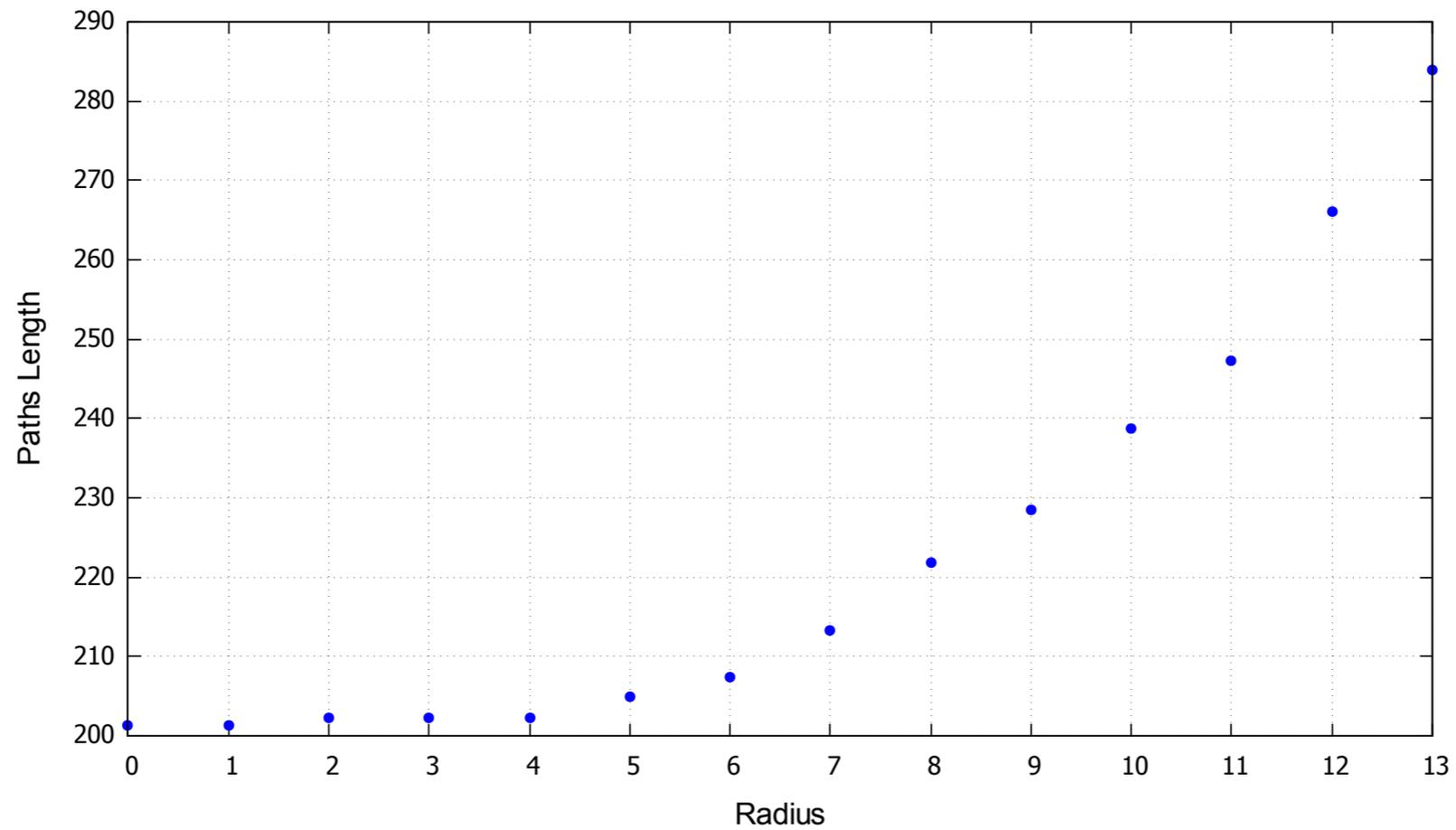


Each tree:
within approximately
2 CPU hours
(105 B&B nodes)

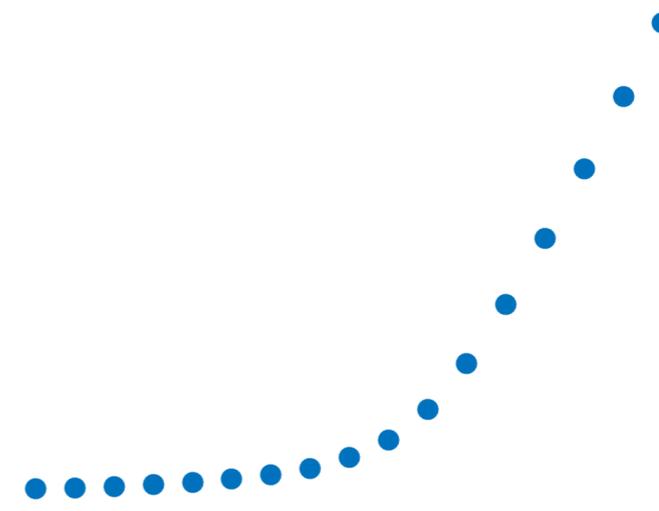
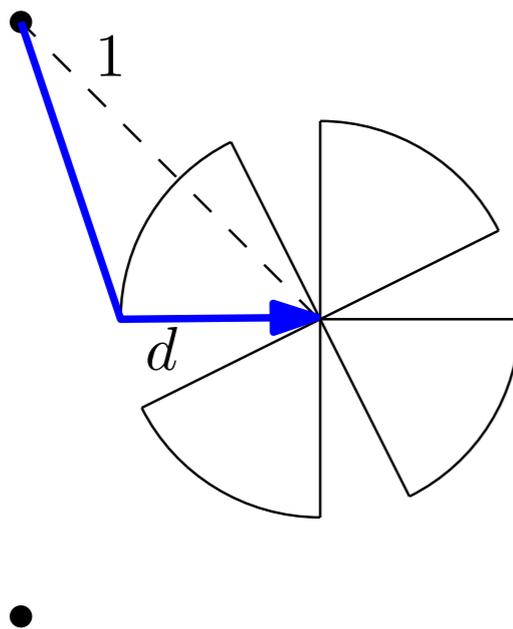
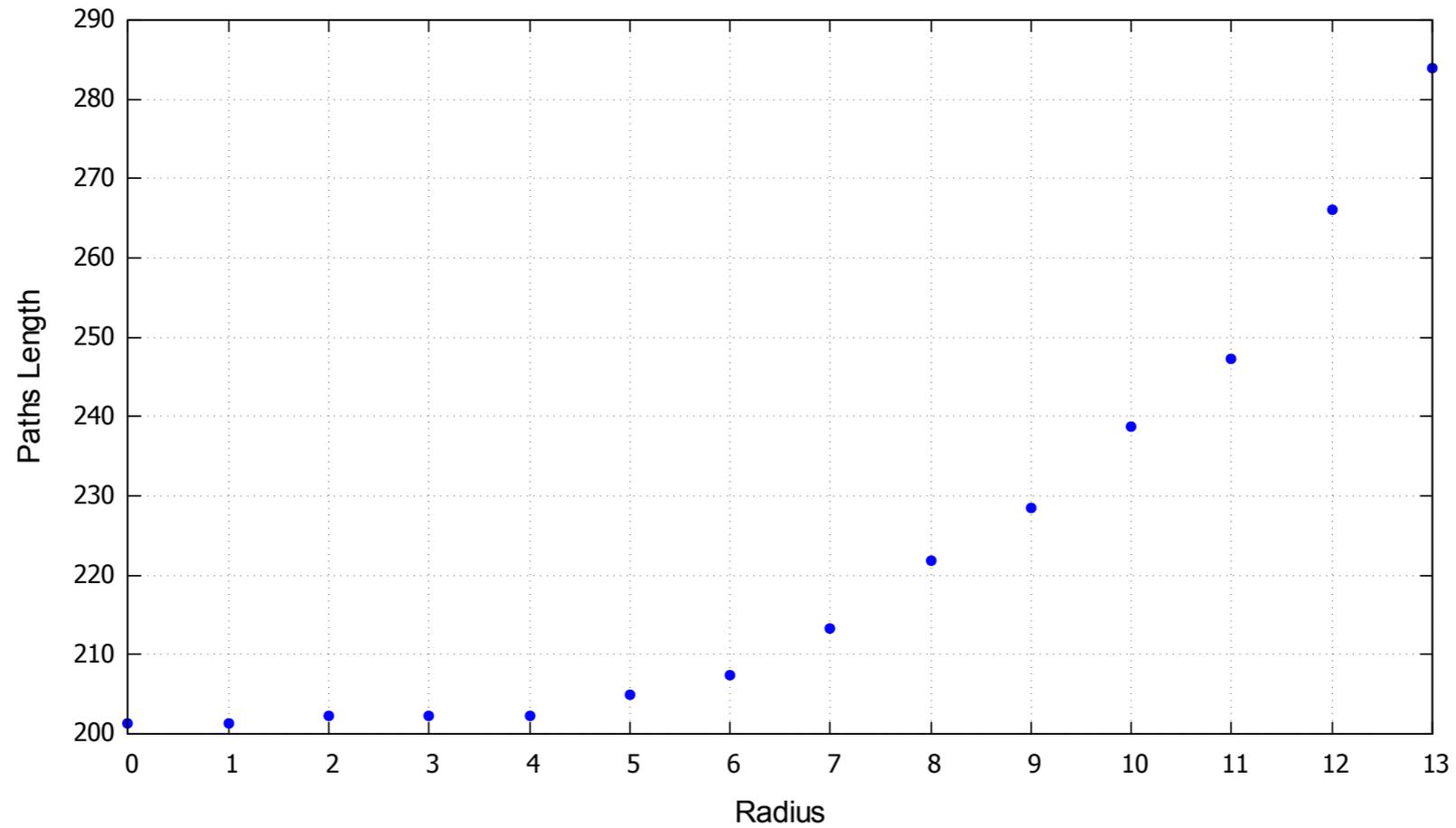
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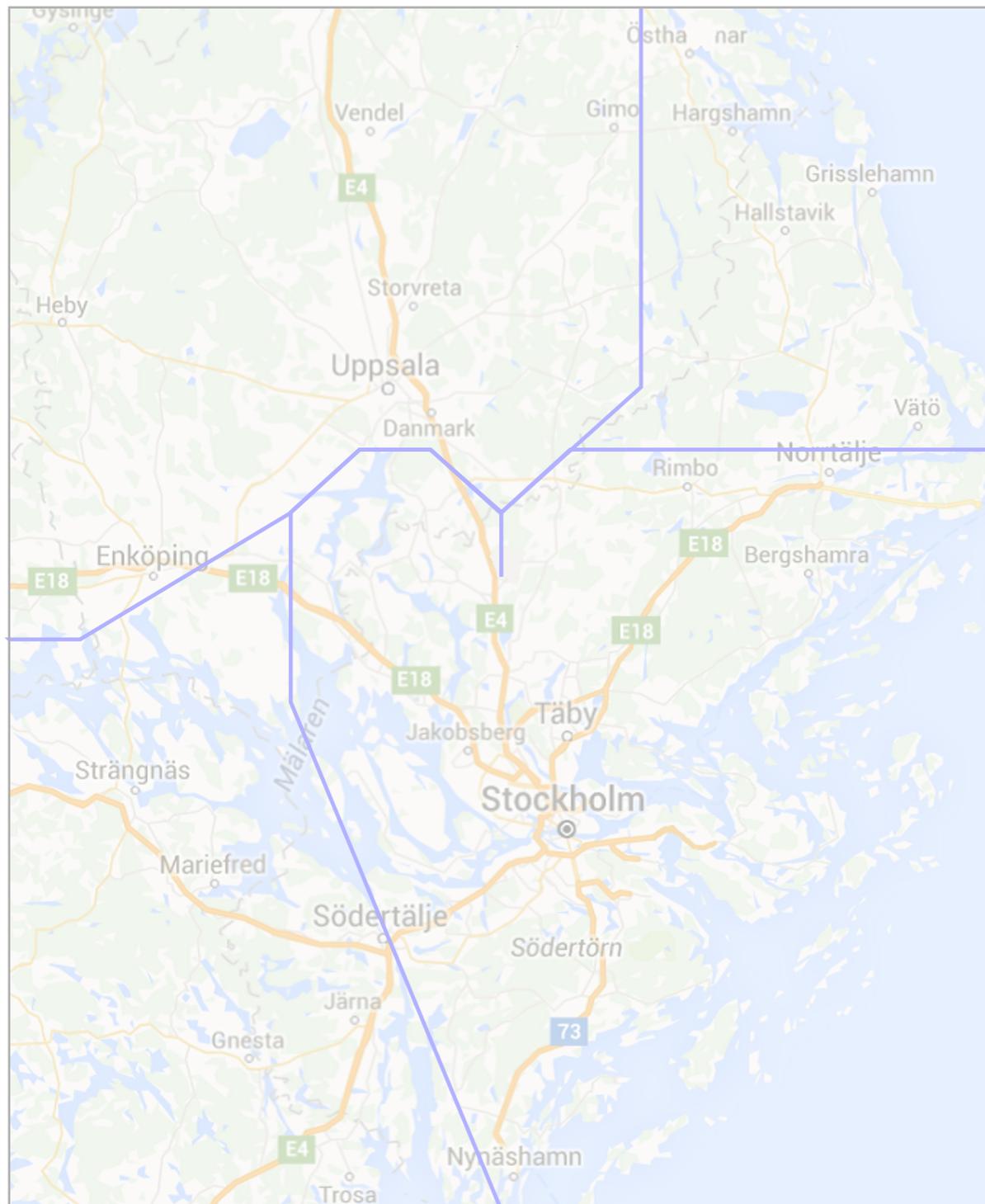
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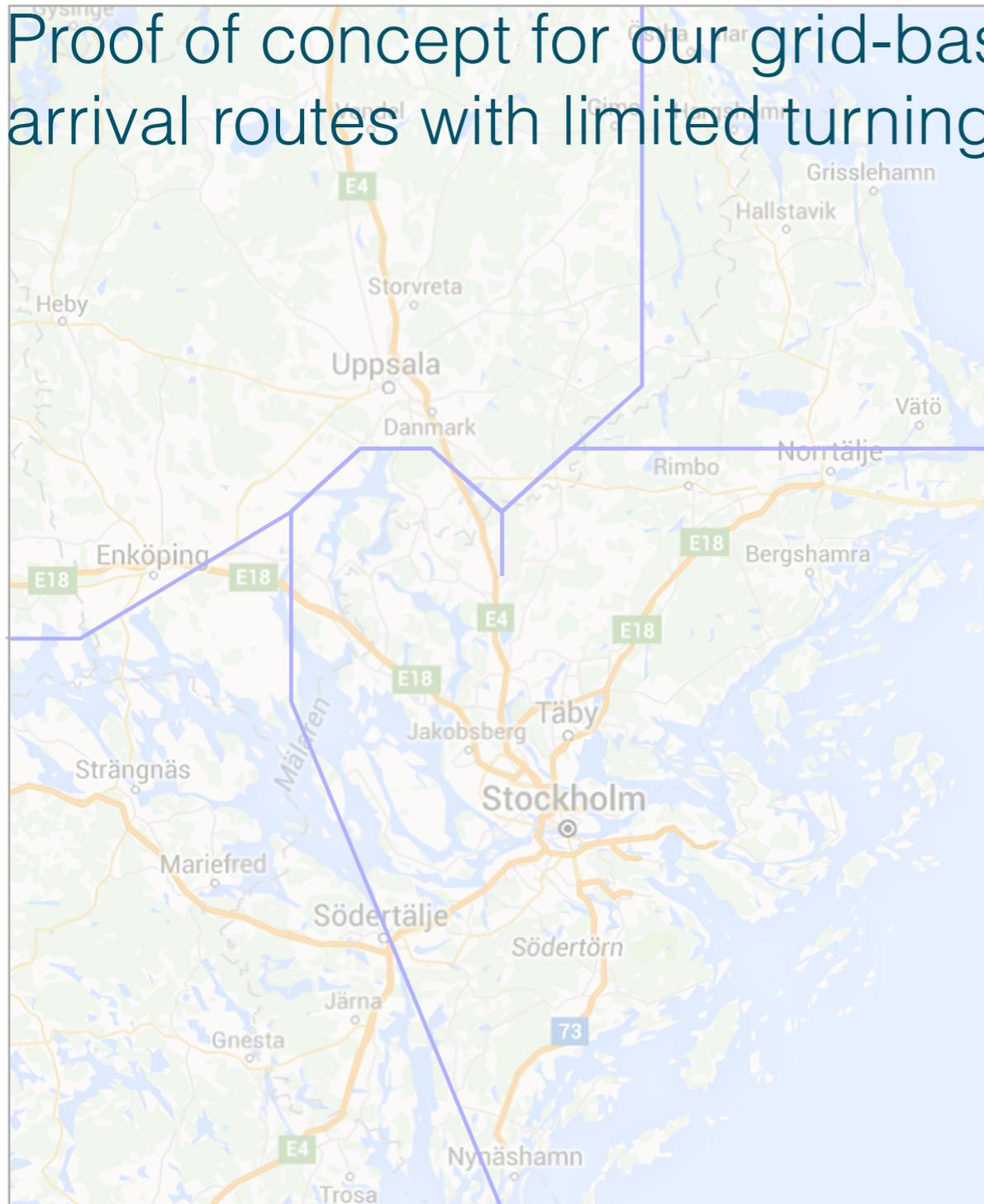
SID constraints:



Conclusion/Outlook

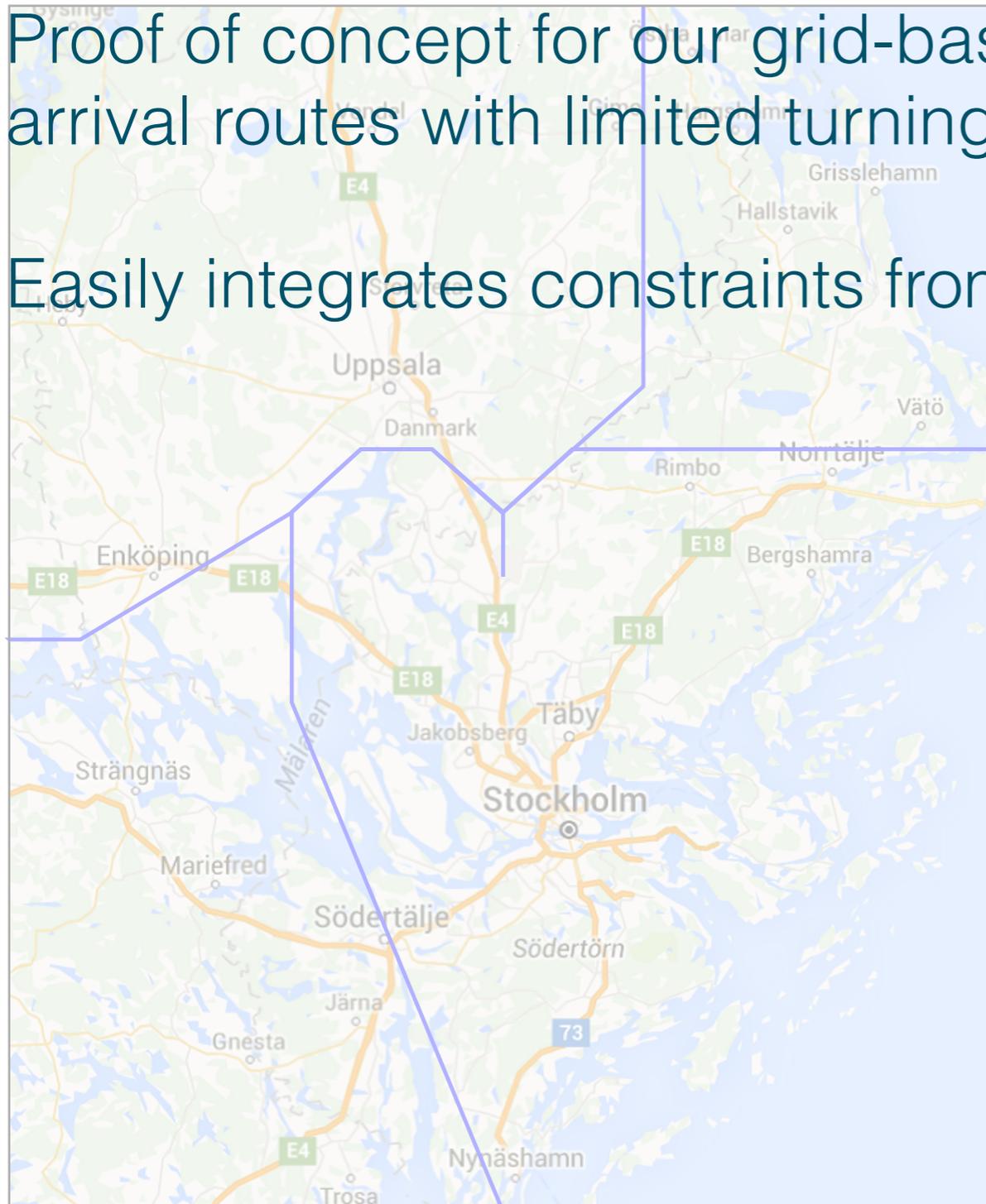


Proof of concept for our grid-based IP approach for finding aircraft arrival routes with limited turning angle



Proof of concept for our grid-based IP approach for finding aircraft arrival routes with limited turning angle

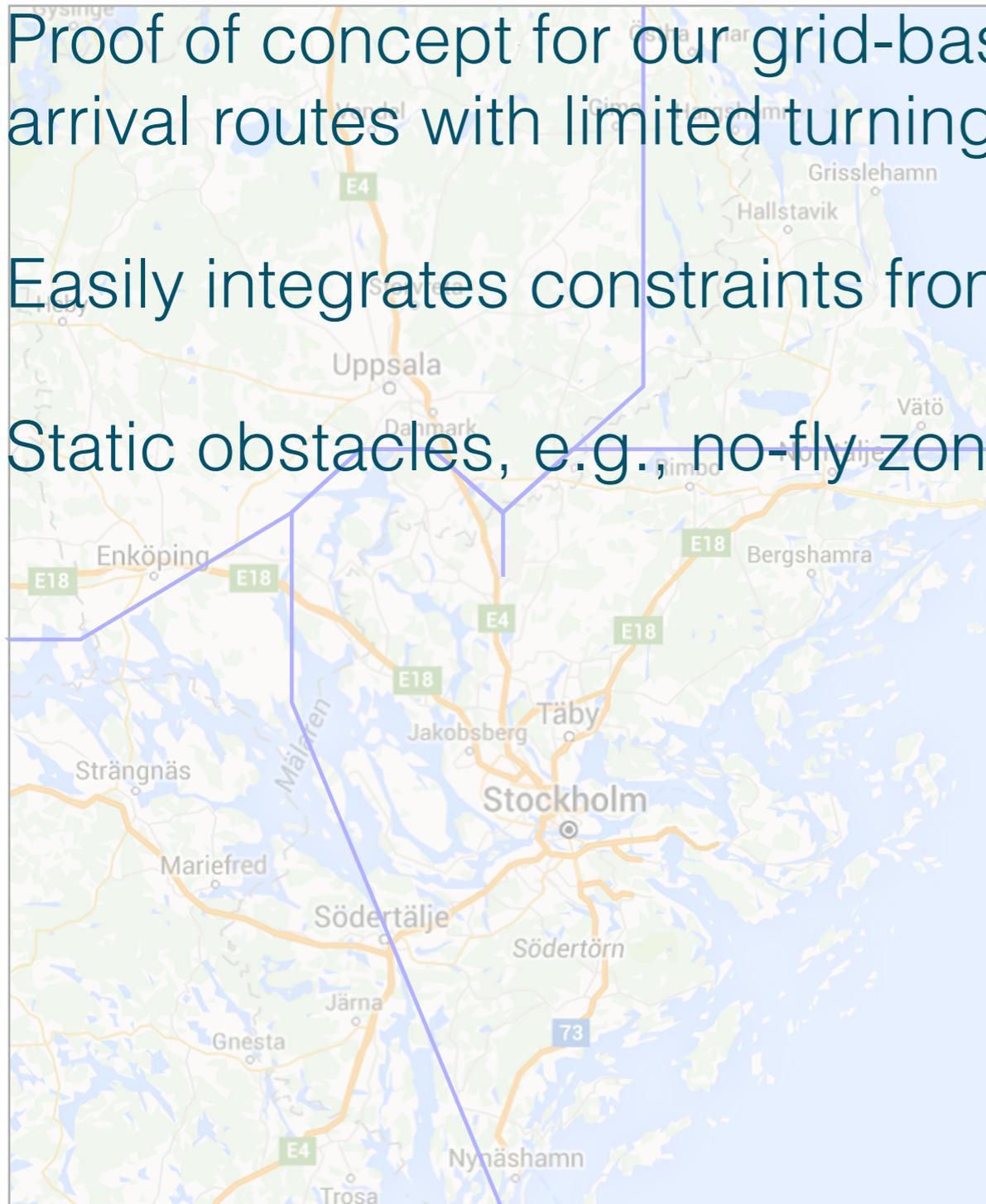
Easily integrates constraints from the departure routes



Proof of concept for our grid-based IP approach for finding aircraft arrival routes with limited turning angle

Easily integrates constraints from the departure routes

Static obstacles, e.g., no-fly zones, can be added

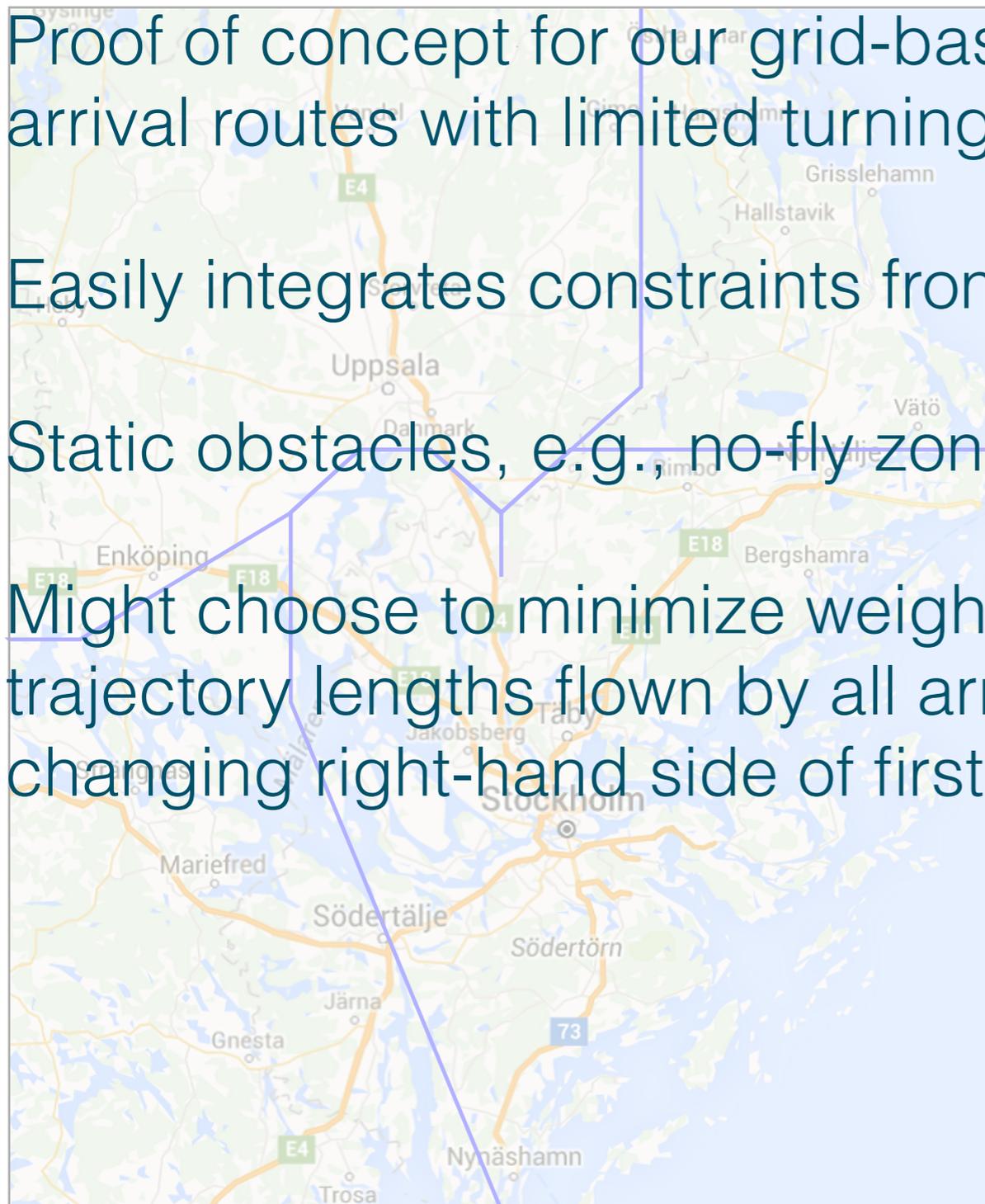


Proof of concept for our grid-based IP approach for finding aircraft arrival routes with limited turning angle

Easily integrates constraints from the departure routes

Static obstacles, e.g., no-fly zones, can be added

Might choose to minimize weighted version: minimize the sum of trajectory lengths flown by all arriving aircraft (easily integrated by changing right-hand side of first equation)



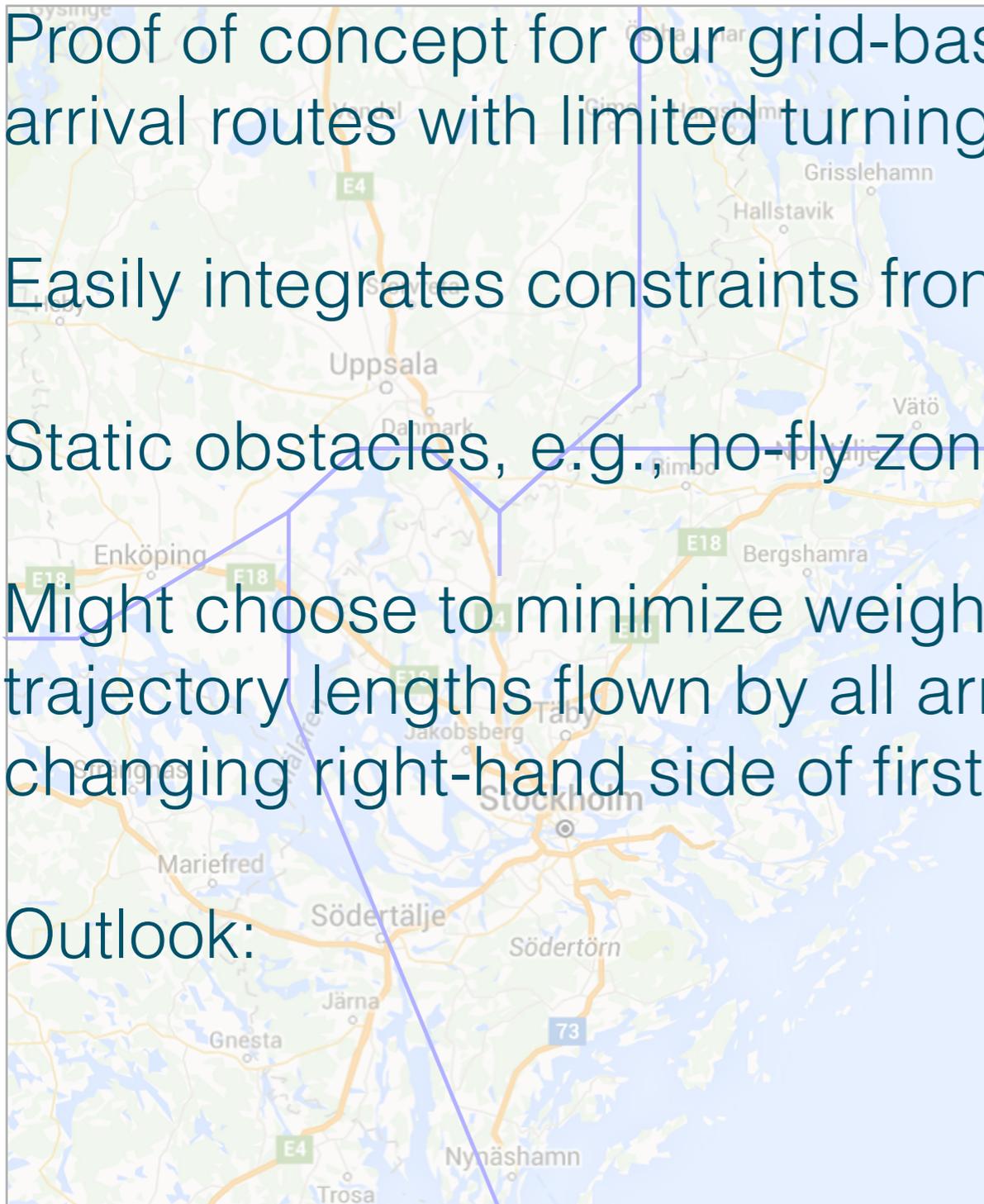
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Outlook:



Proof of concept for our grid-based IP approach for finding aircraft arrival routes with limited turning angle

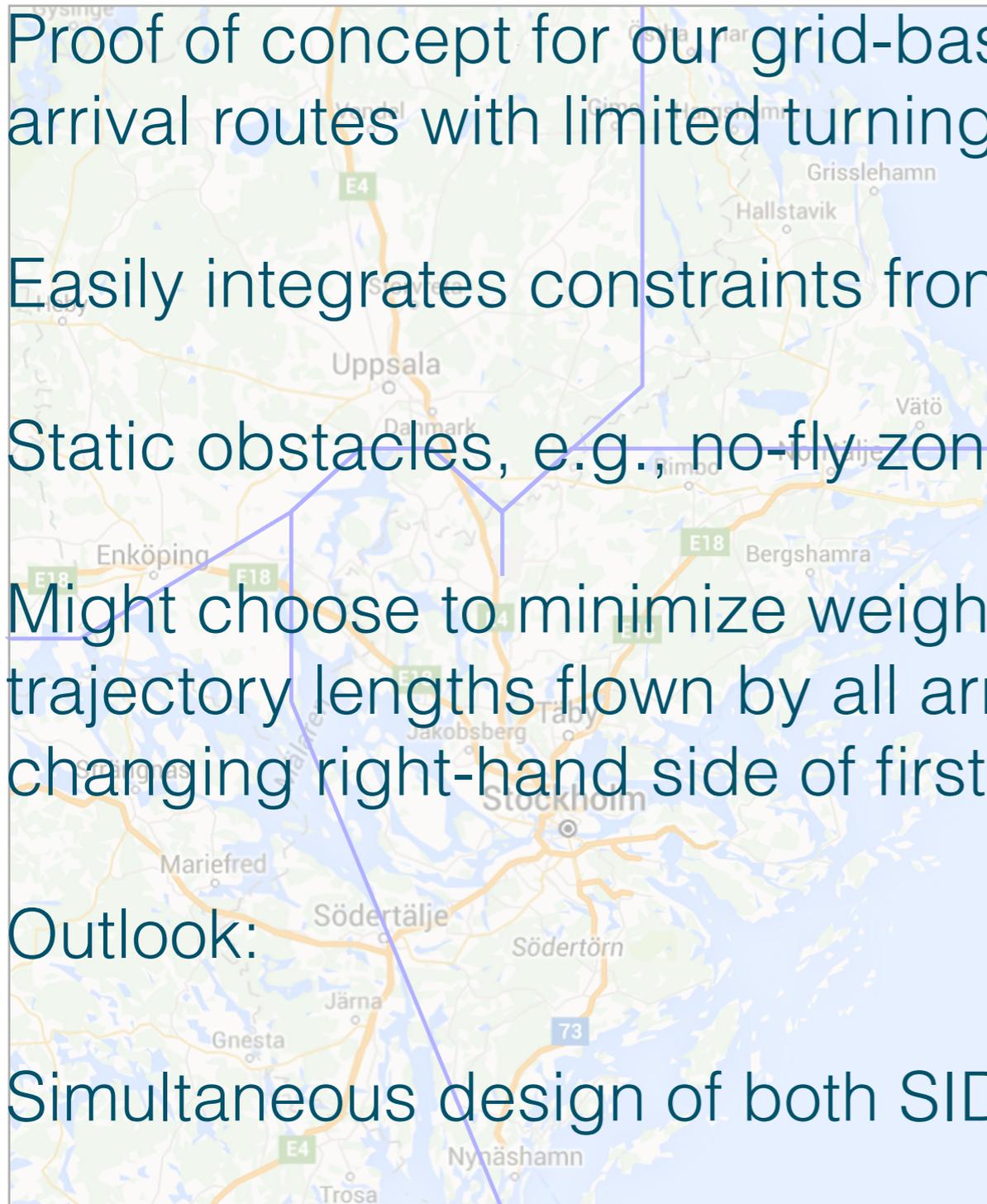
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Outlook:

Simultaneous design of both SIDs and STARs



Proof of concept for our grid-based IP approach for finding aircraft arrival routes with limited turning angle

Easily integrates constraints from the departure routes

Static obstacles, e.g., no-fly zones, can be added

Might choose to minimize weighted version: minimize the sum of trajectory lengths flown by all arriving aircraft (easily integrated by changing right-hand side of first equation)

Outlook:

Simultaneous design of both SIDs and STARs

3D routes

