

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

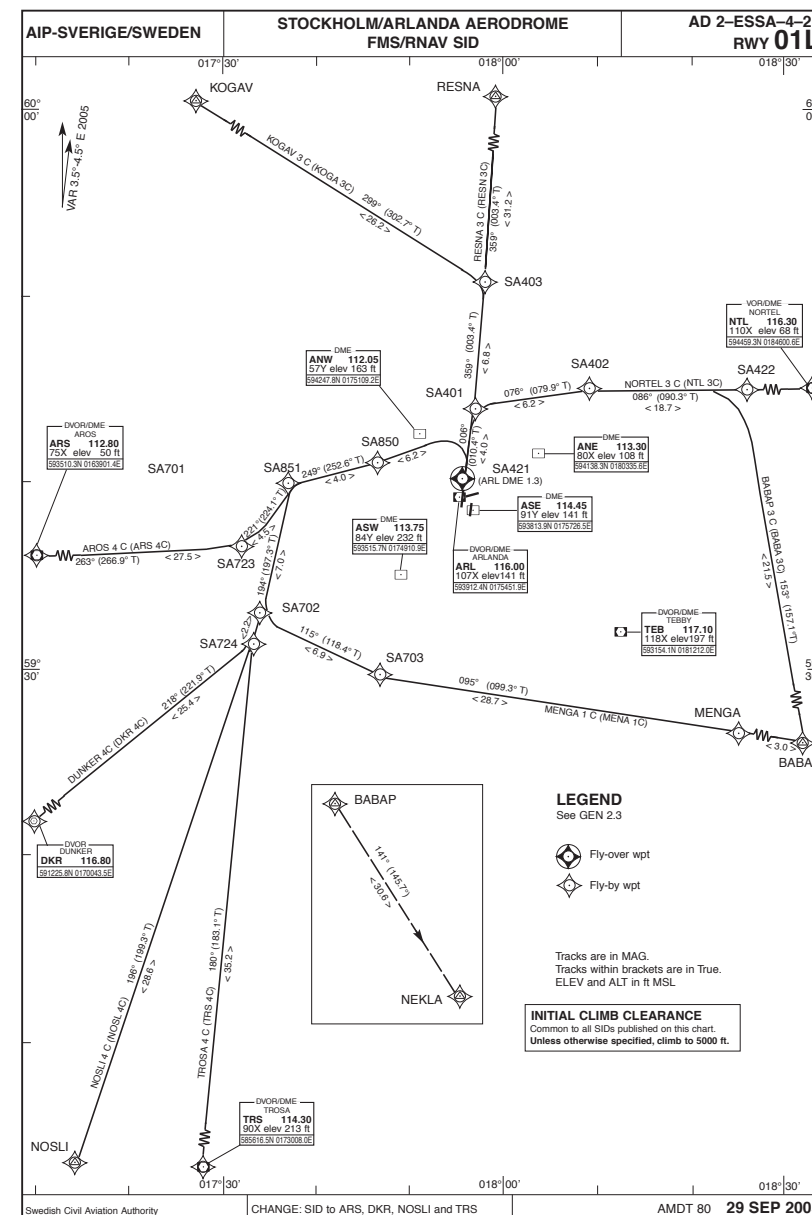


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Standard Instrument Departures (SIDs) and
Standard Terminal Arrival Routes (STARs)

SID
Stockholm,
RWY 01L



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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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Degree constraints:

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

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

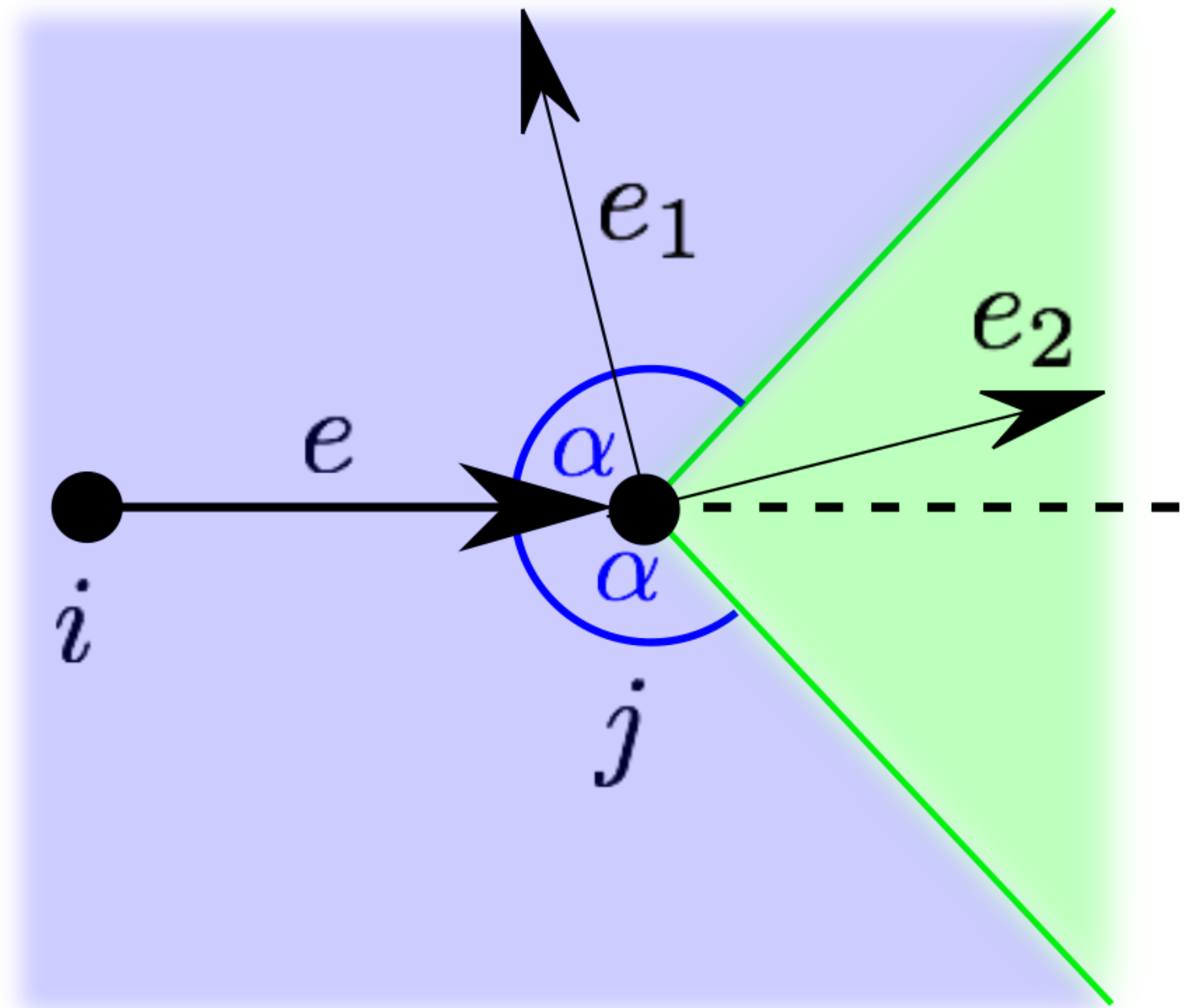
$$\sum_{k:(k,r) \in E} x_{kr} = 1$$

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

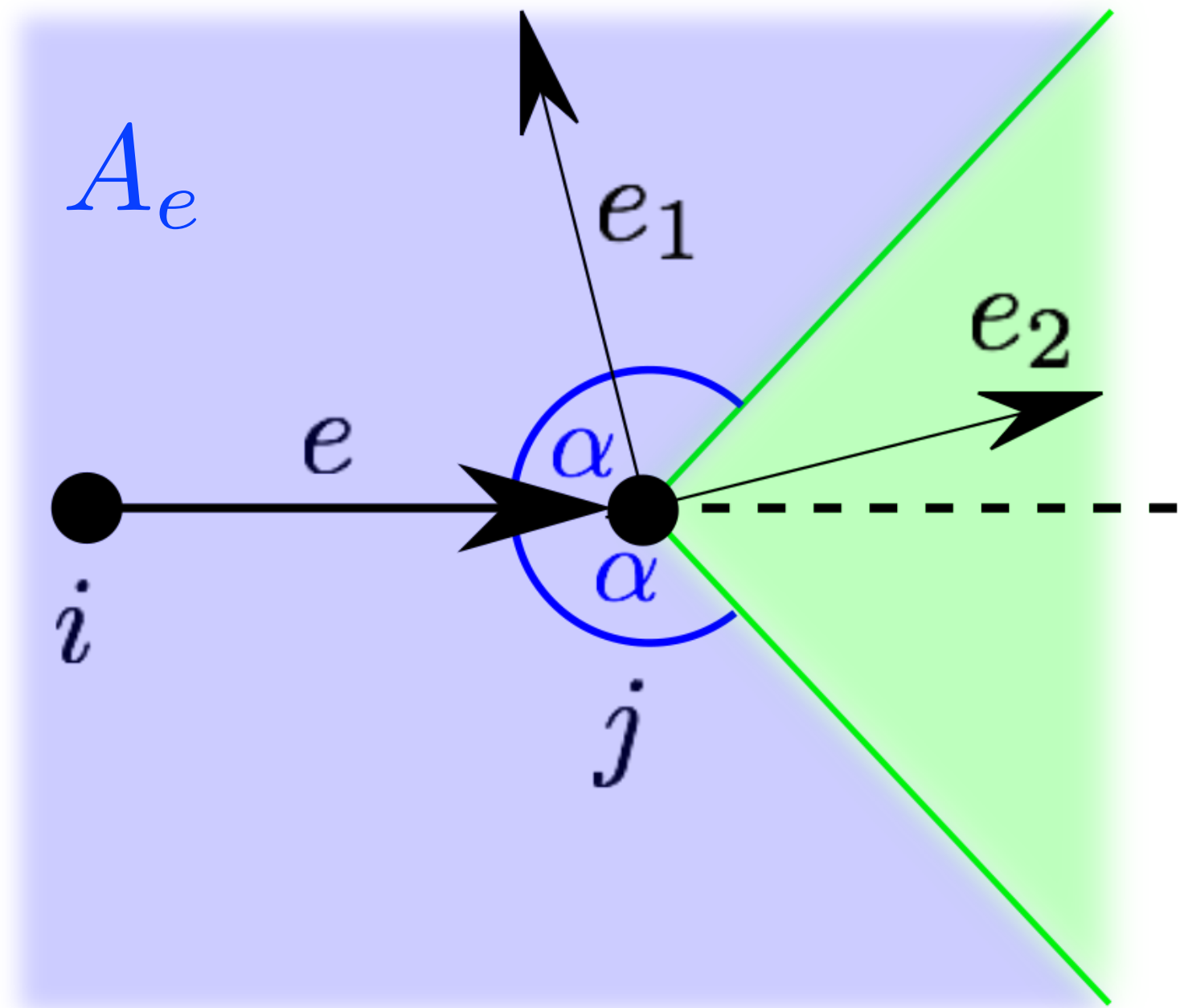
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Turn angle constraints:

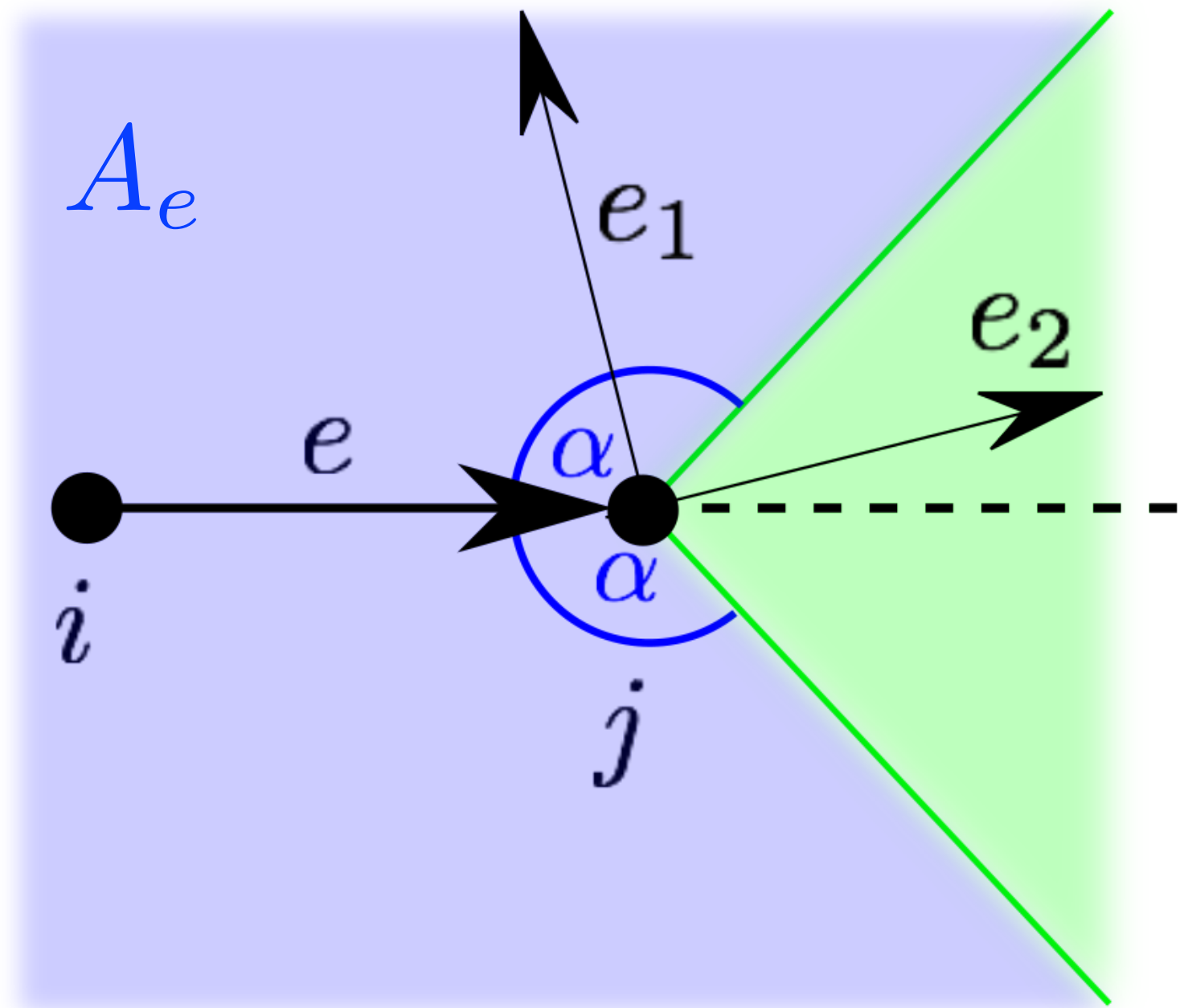


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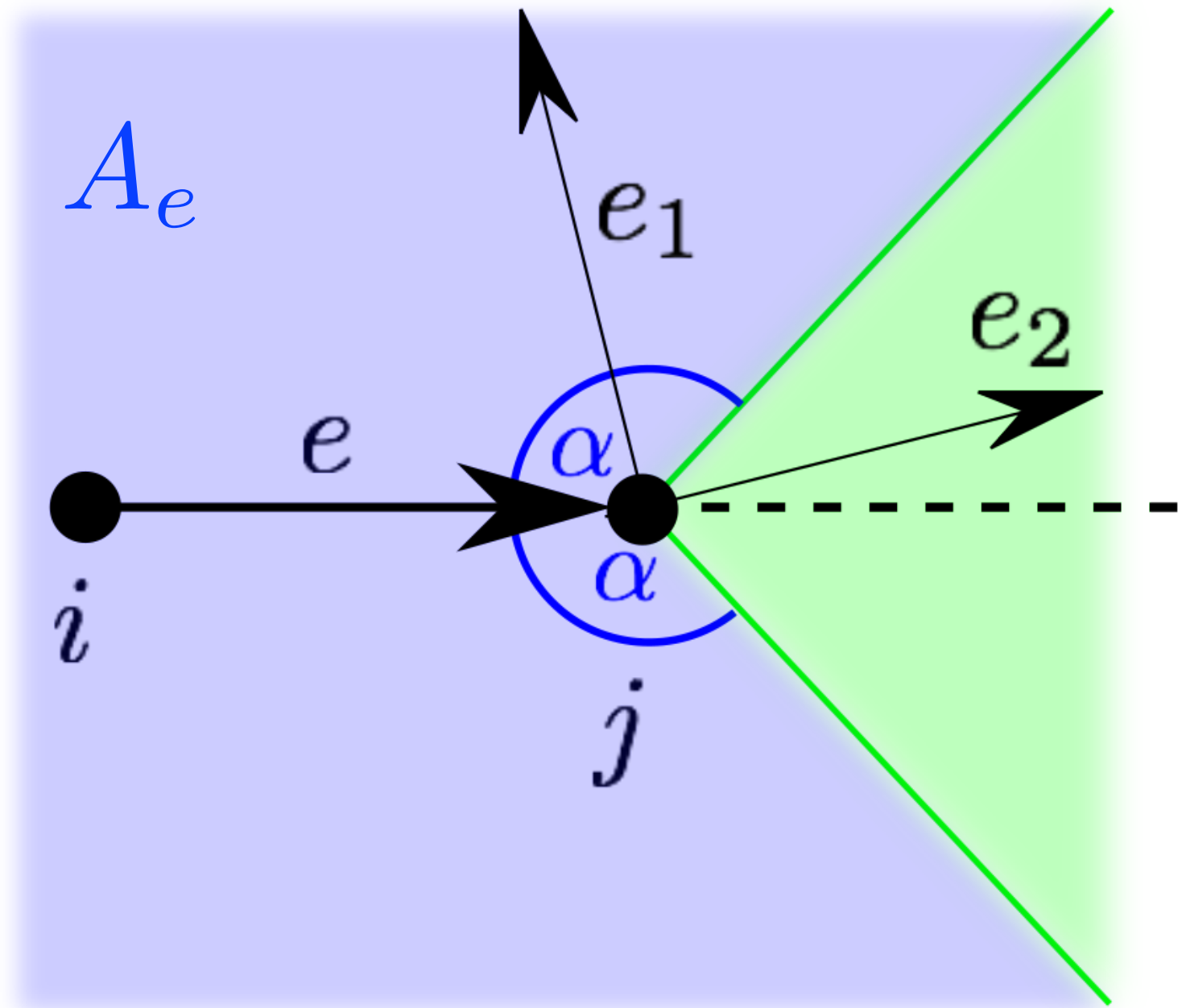
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$$a_e x_e + \sum_{f \in A_e} x_f \leq a_e \quad \forall e \in E$$

SID constraints:

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

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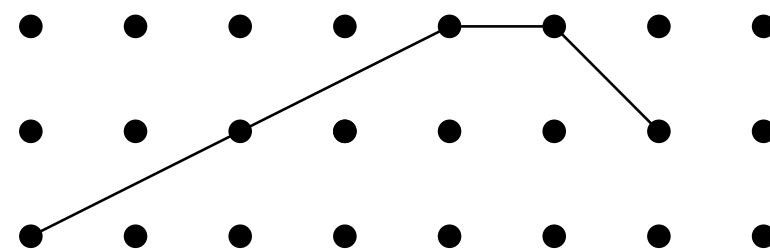
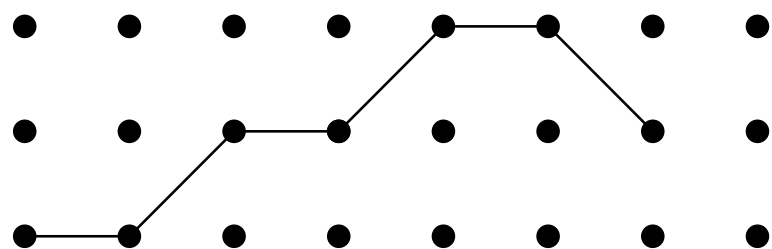
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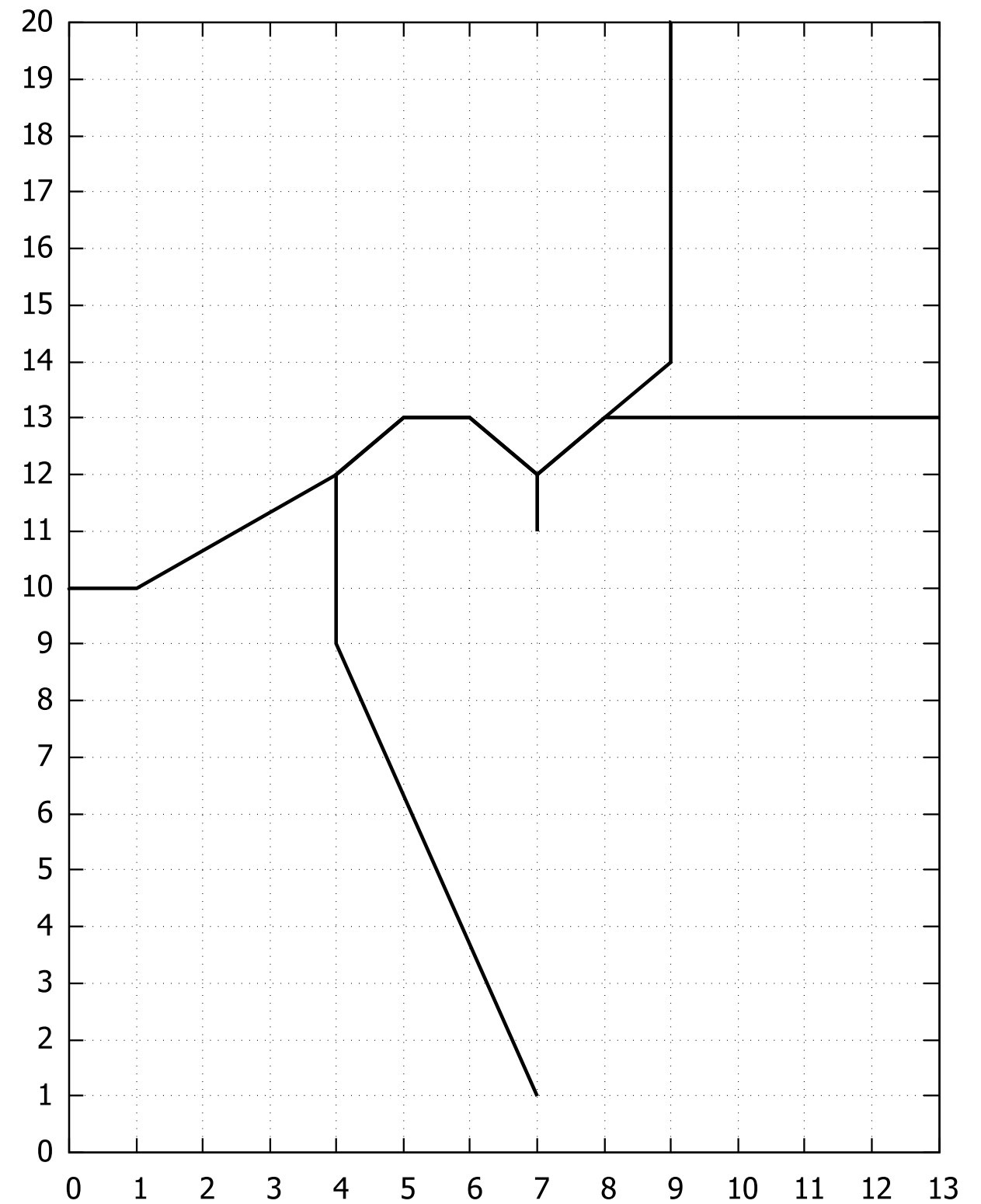
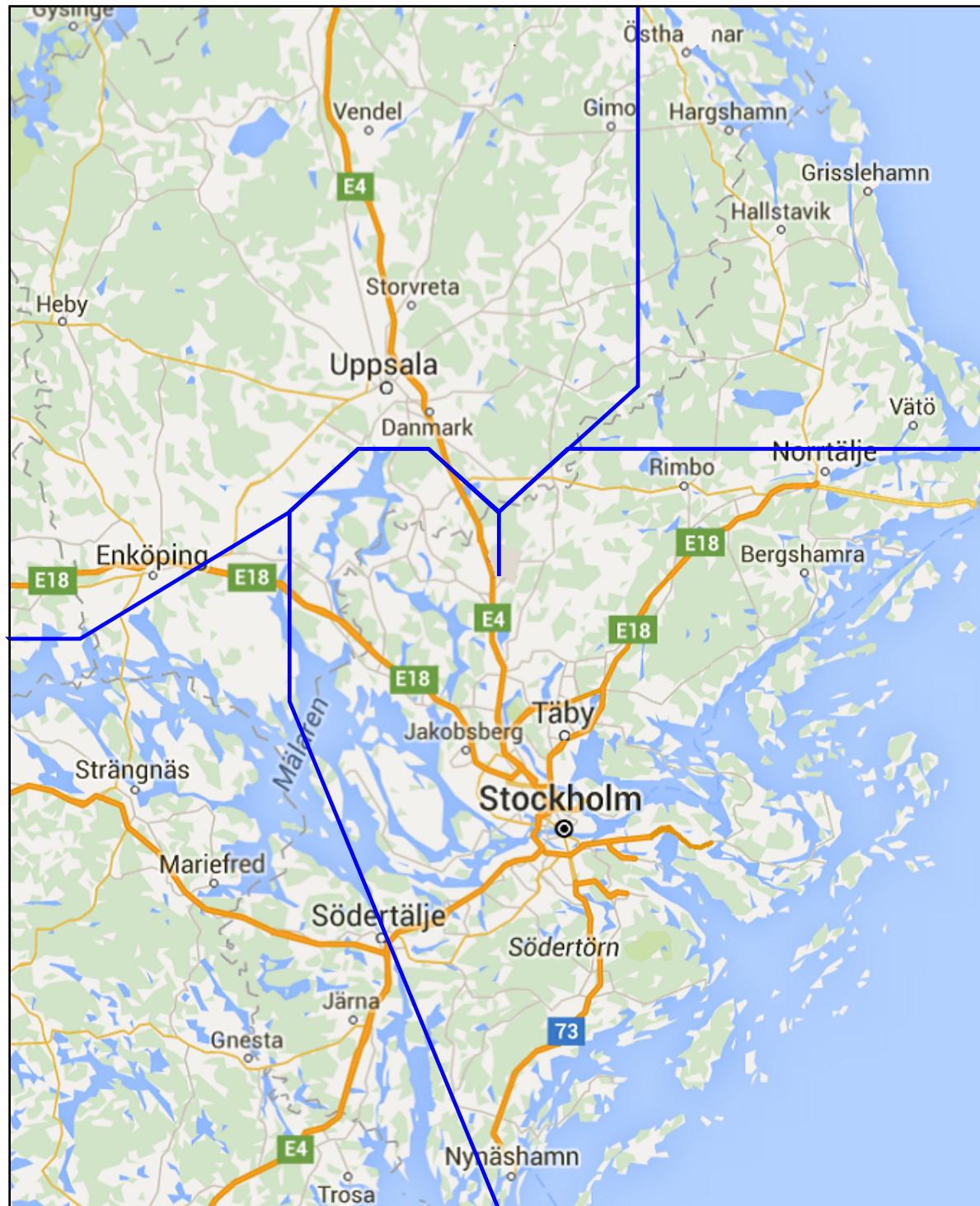
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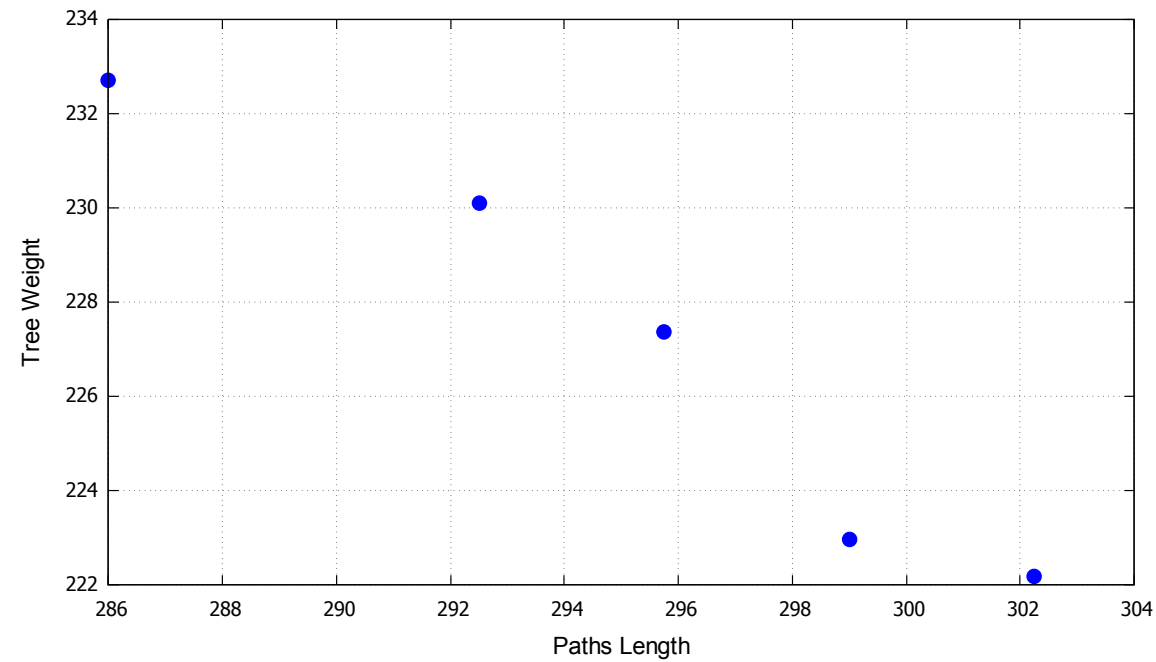
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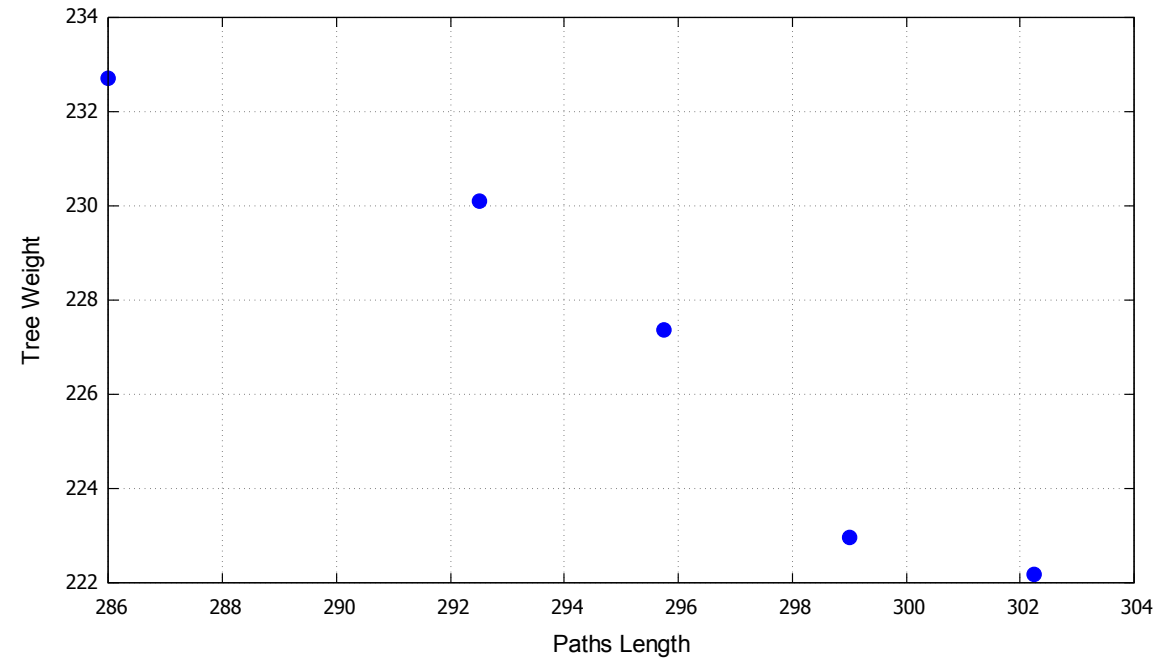




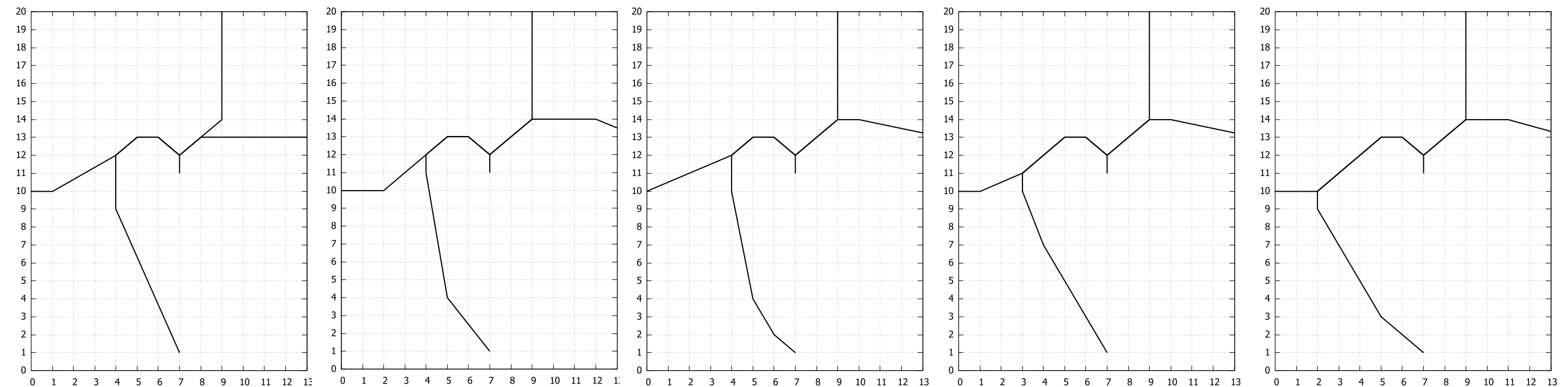
Pareto
frontier:



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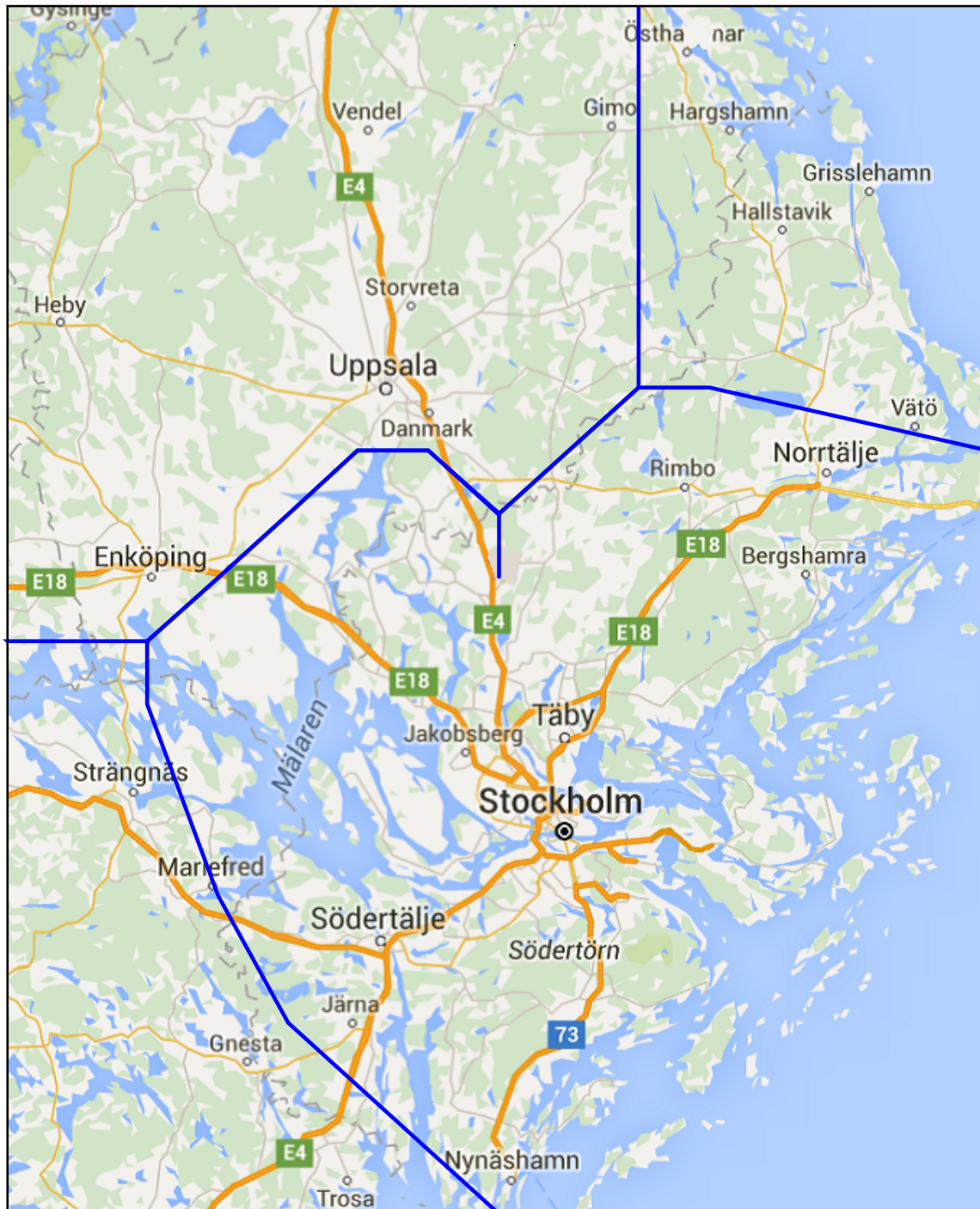


Pareto optimal solutions:

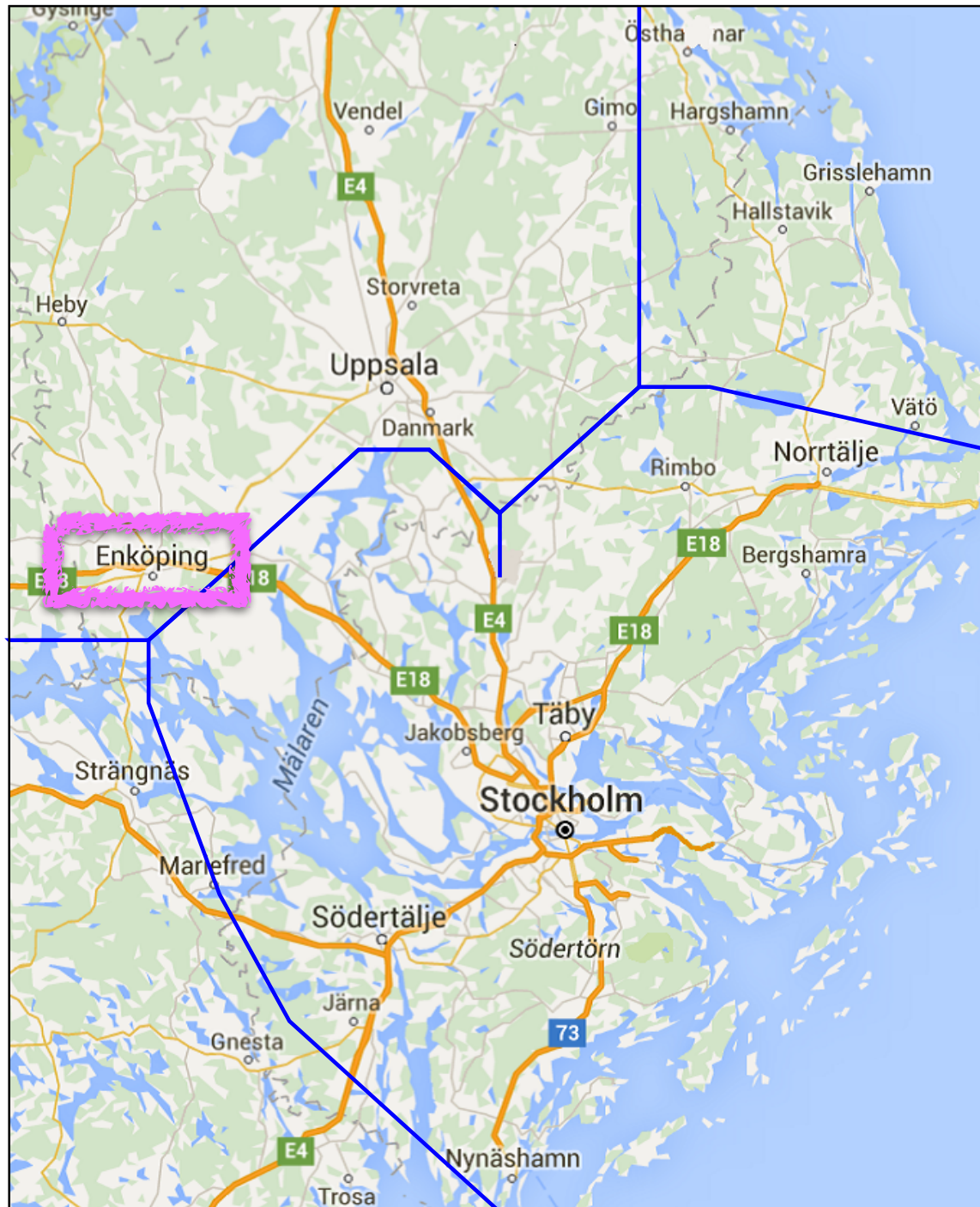


Obstacle avoidance:

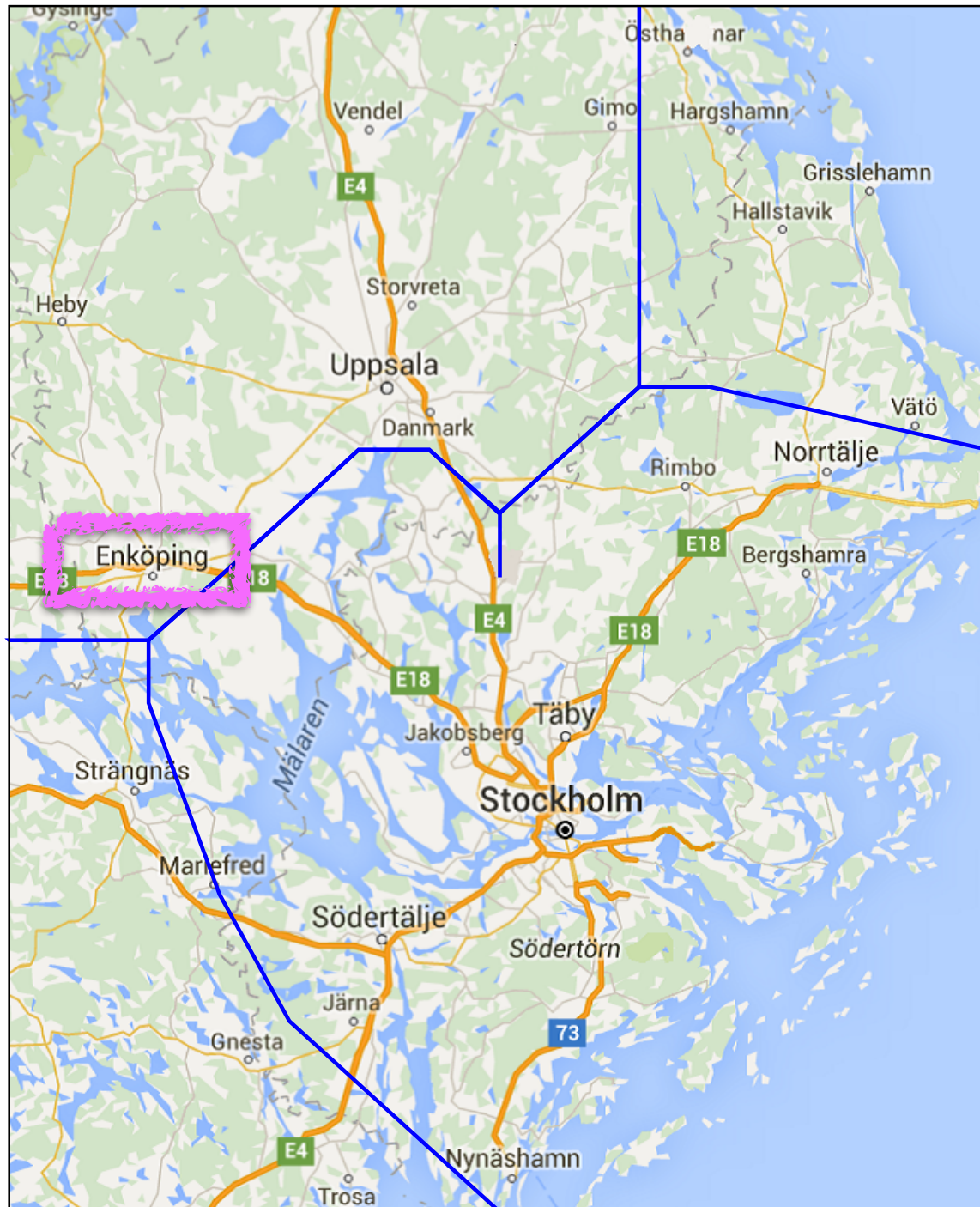
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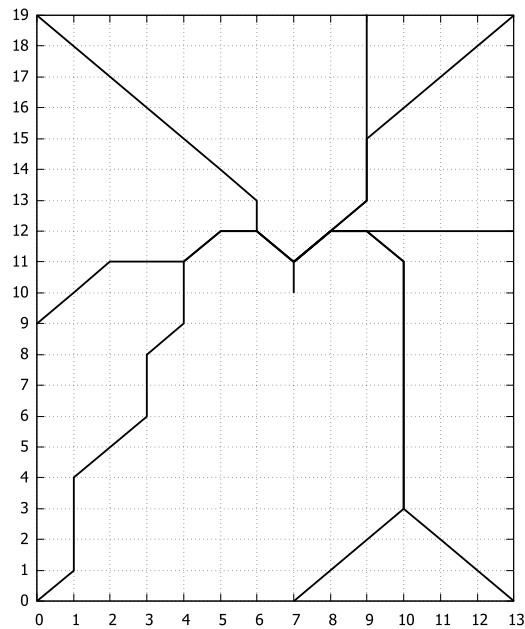
Increased Number of Entry Points:

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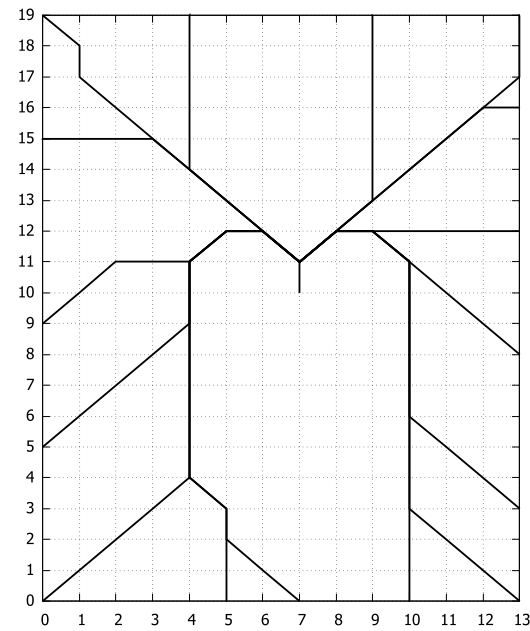
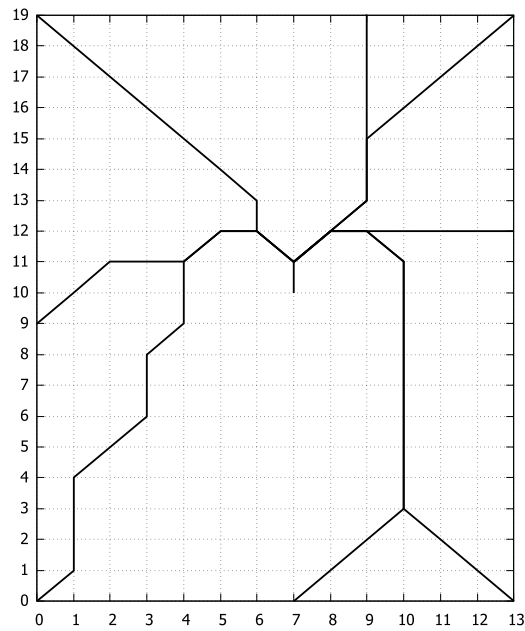
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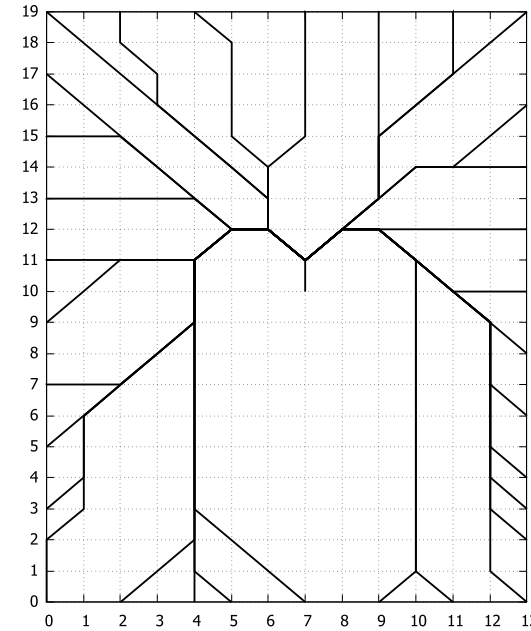
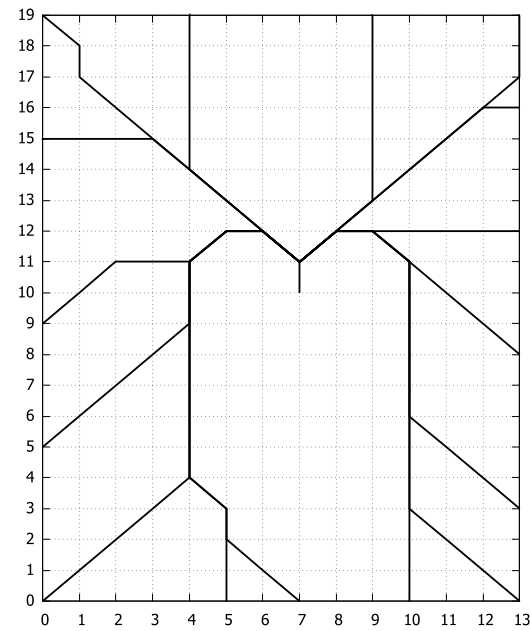
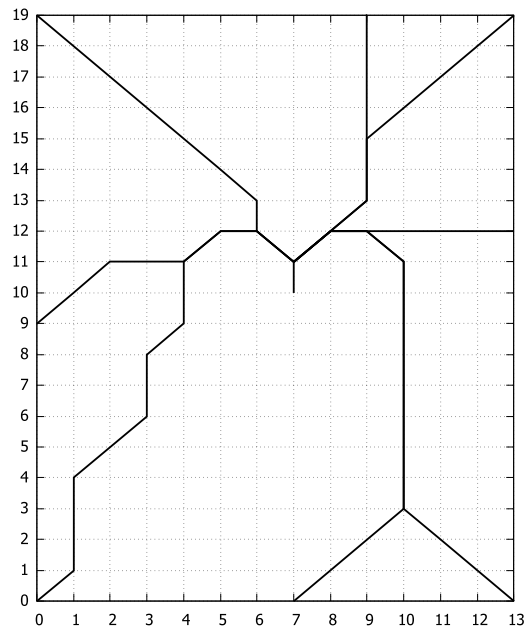
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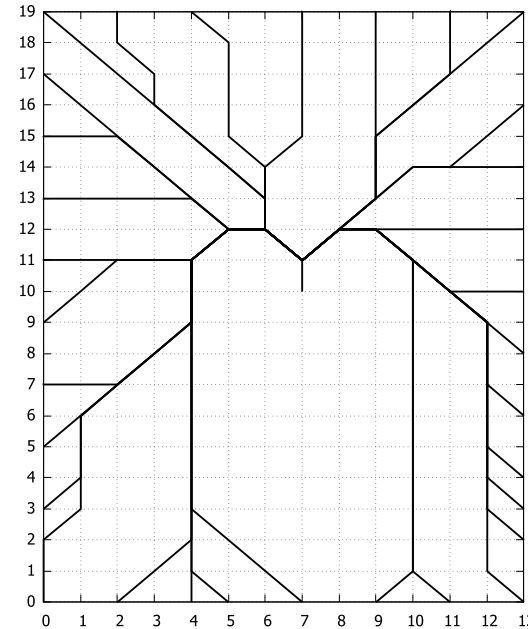
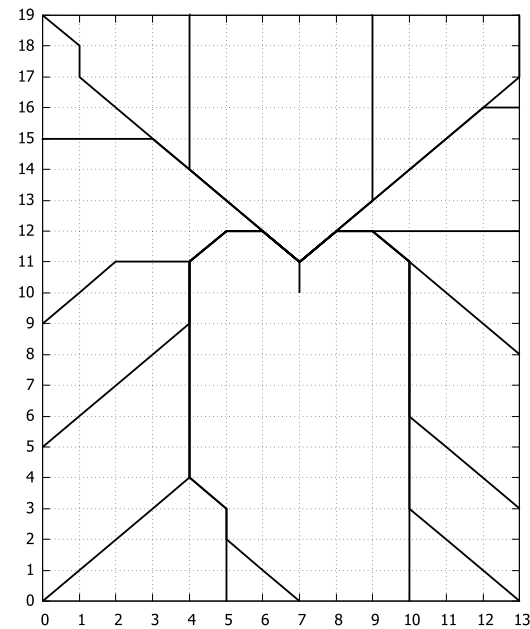
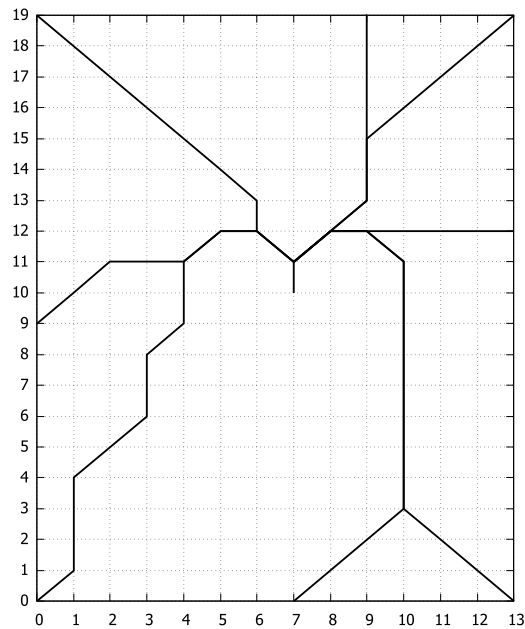
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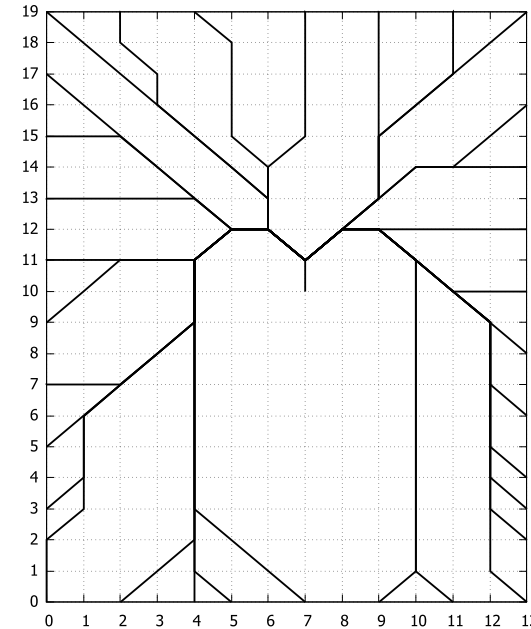
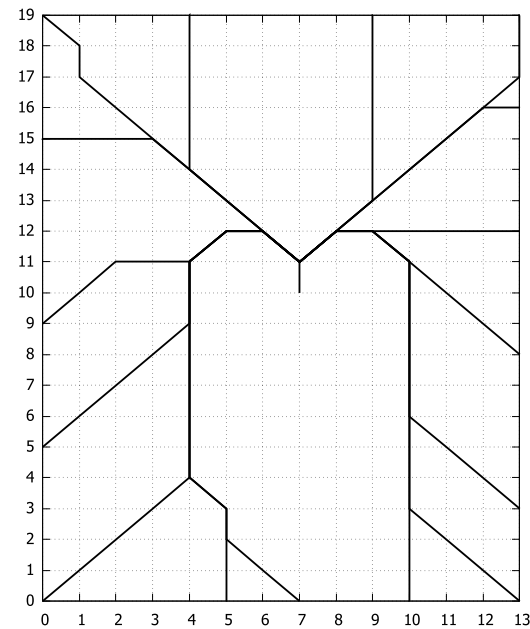
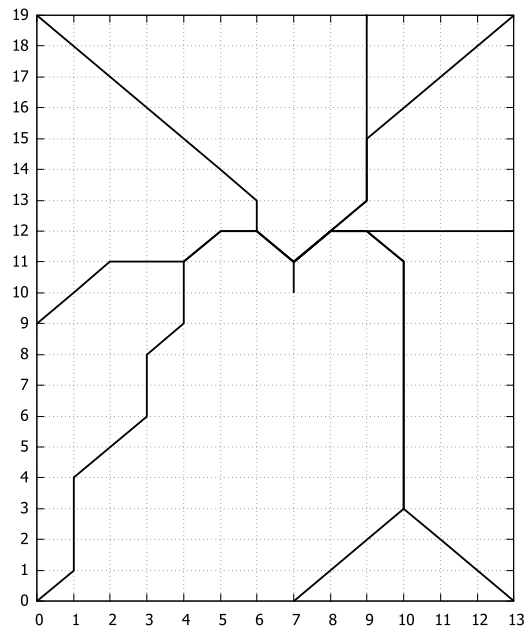
paths length



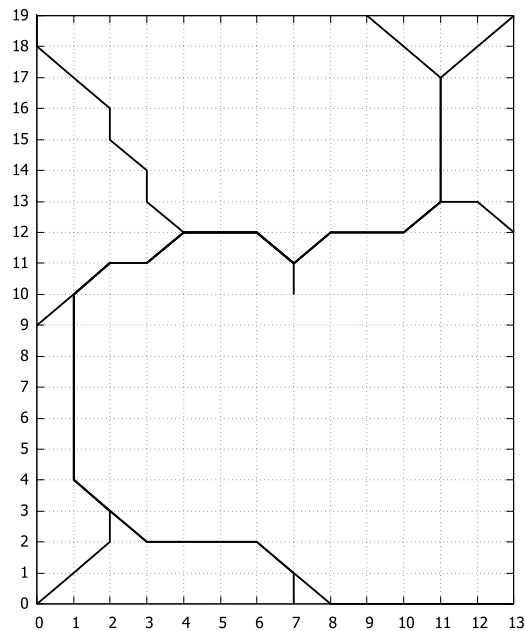
tree weight

Increased Number of Entry Points:

paths length

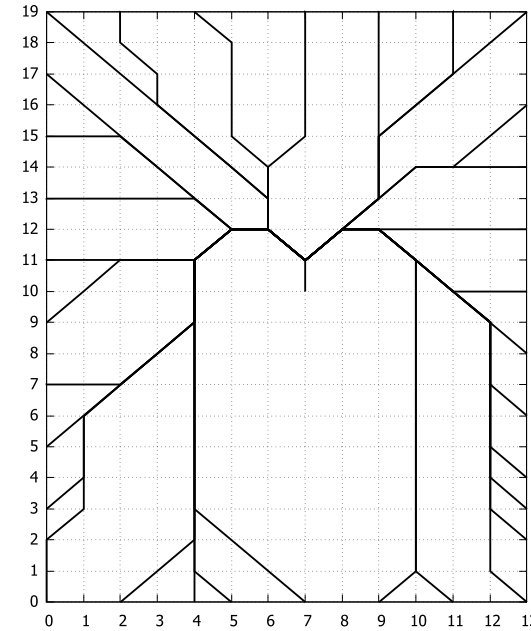
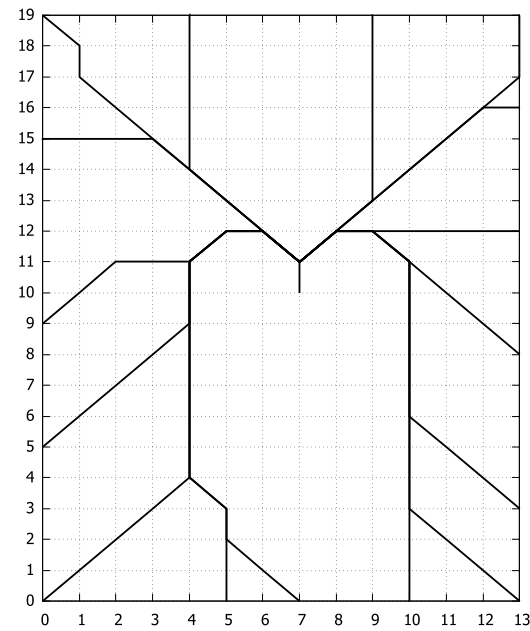
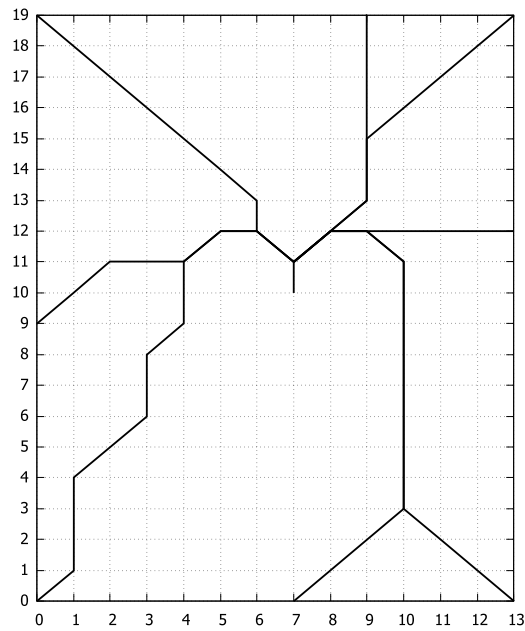


tree weight

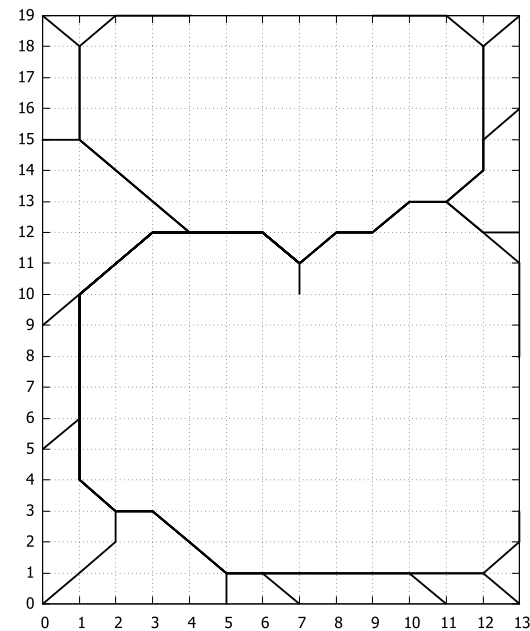
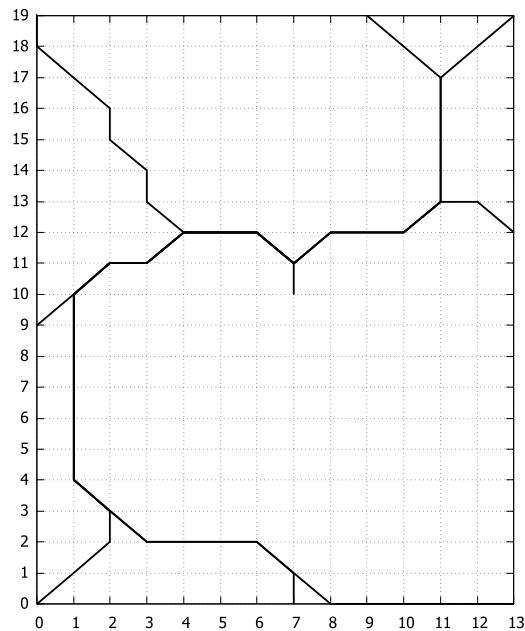


Increased Number of Entry Points:

paths length

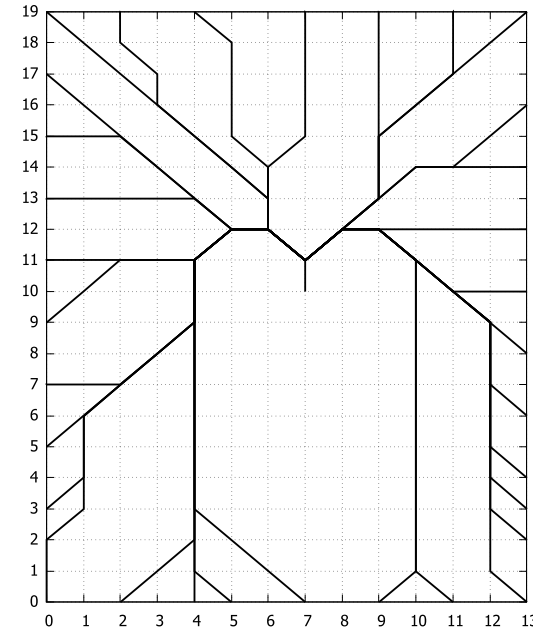
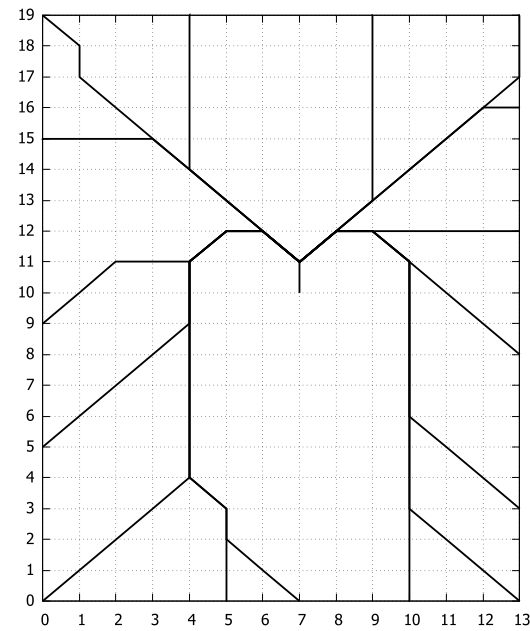
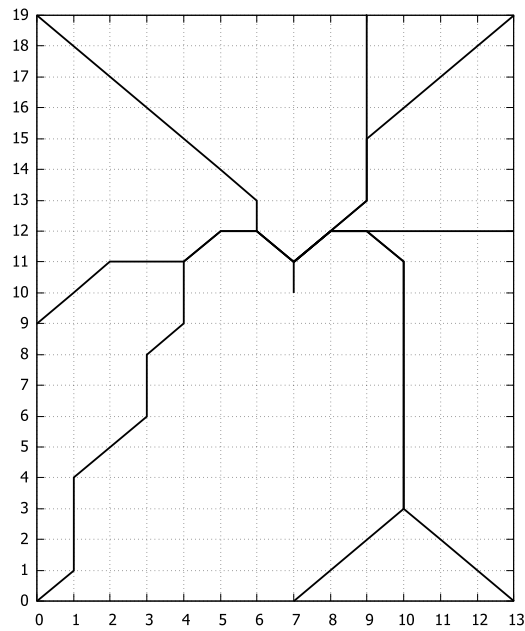


tree weight

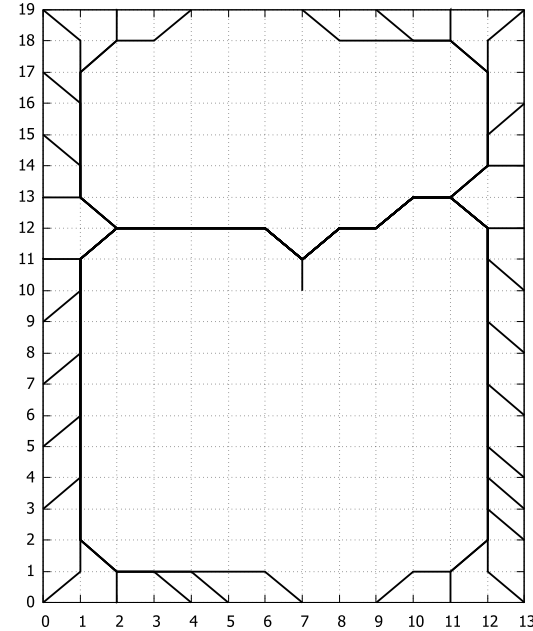
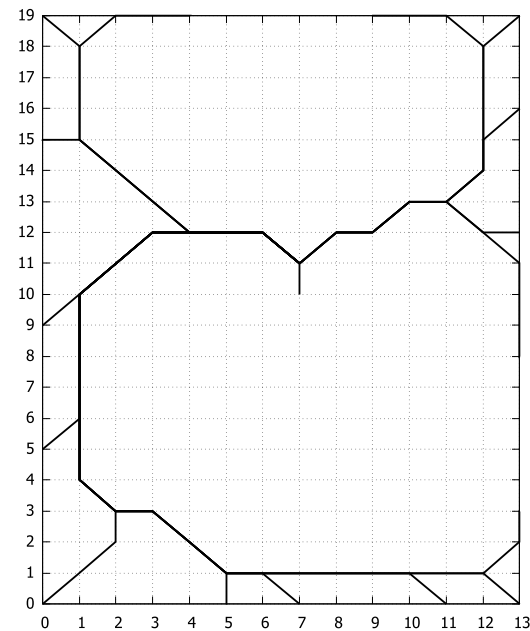
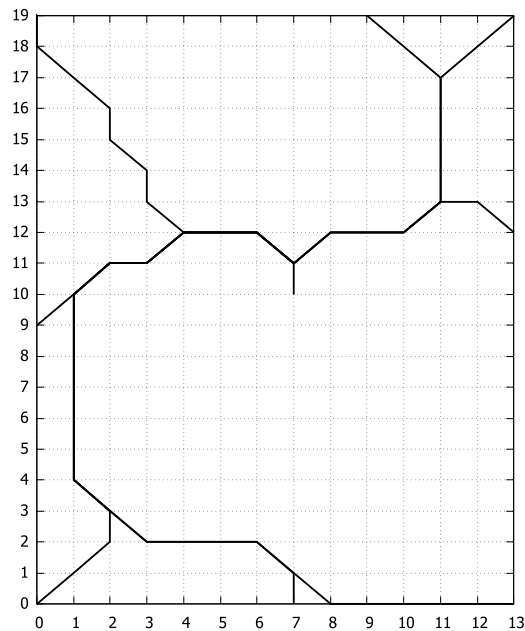


Increased Number of Entry Points:

paths length

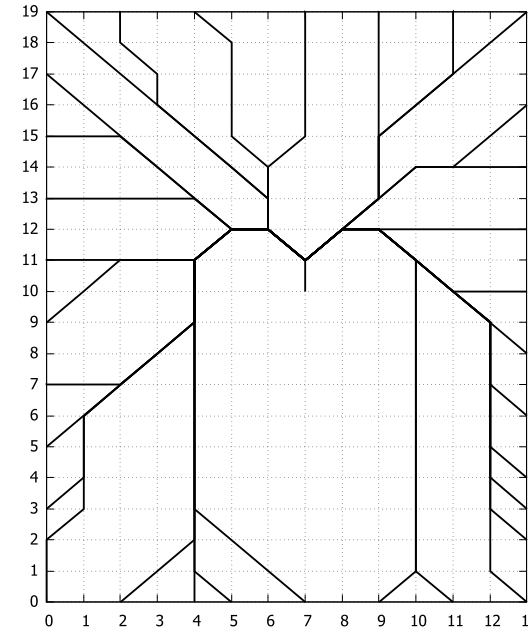
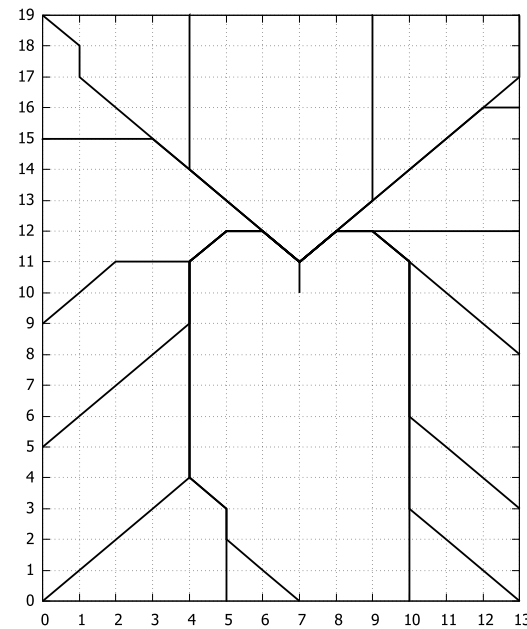
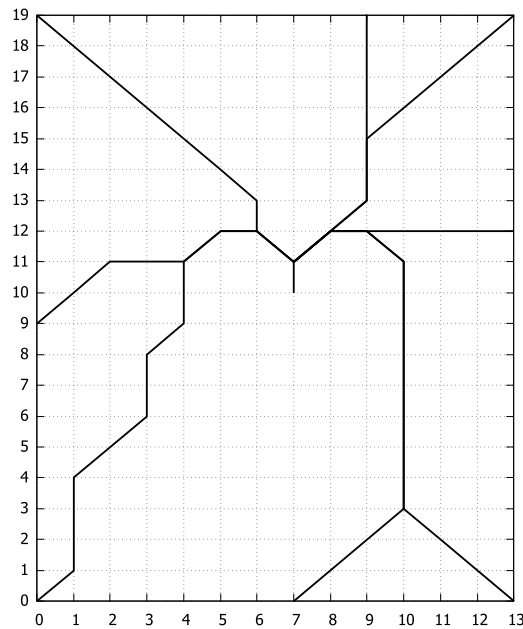


tree weight



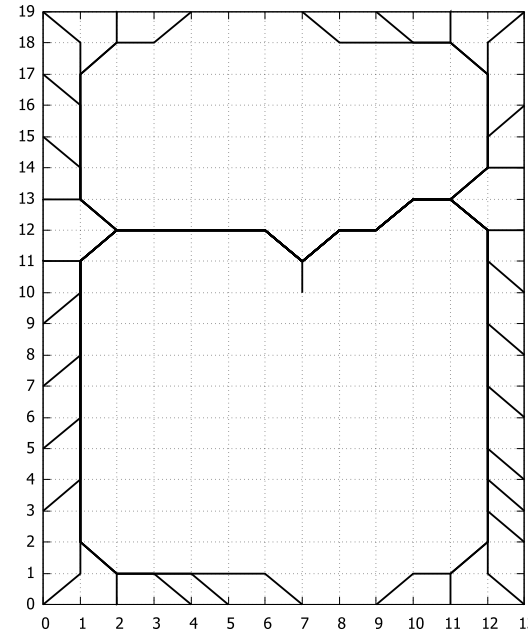
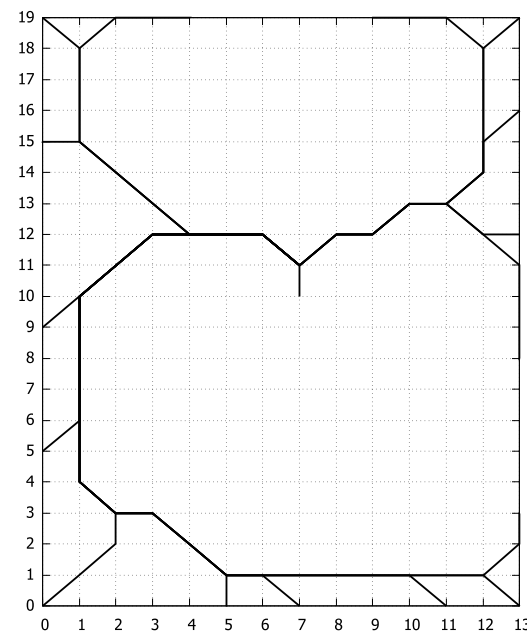
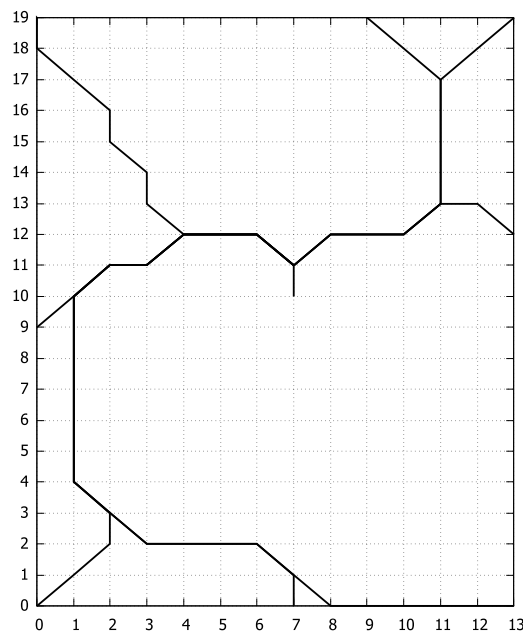
Increased Number of Entry Points:

paths length



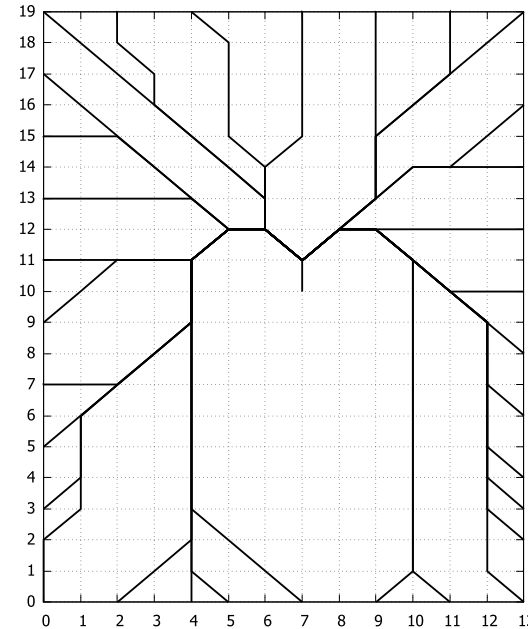
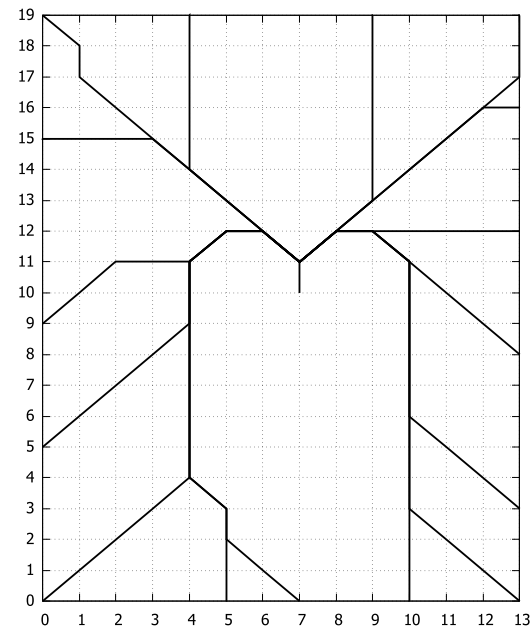
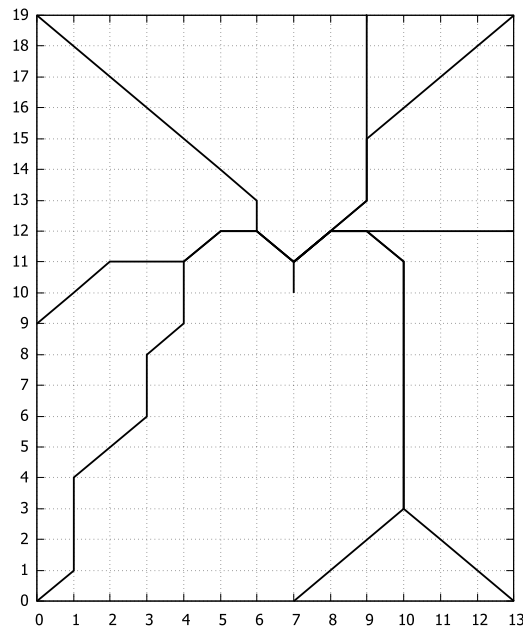
serve the airlines'
request for short
trajectories best

tree weight



Increased Number of Entry Points:

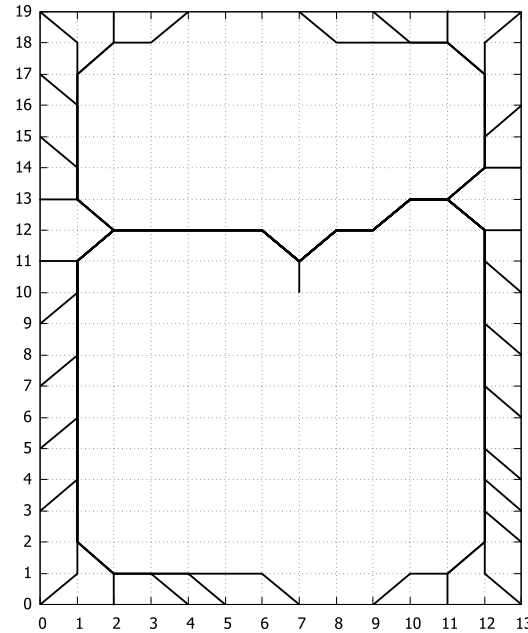
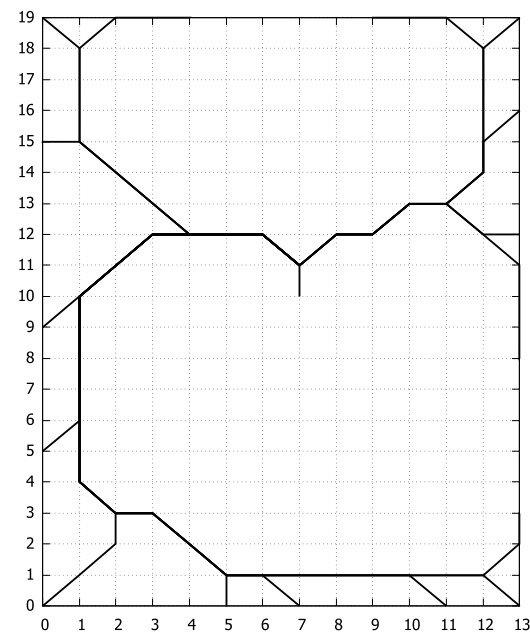
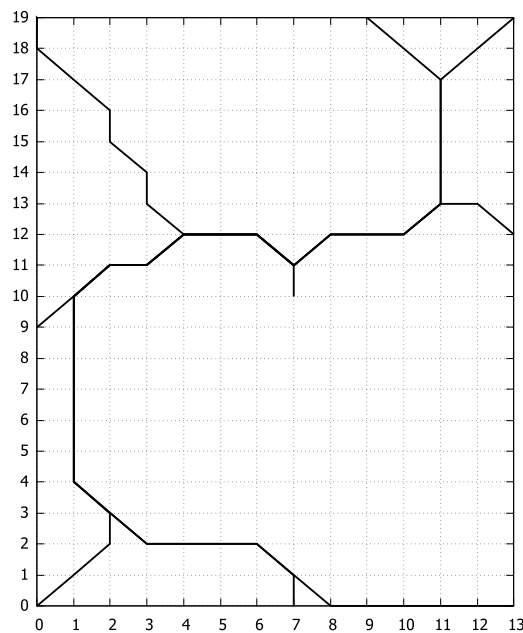
paths length



serve the airlines'
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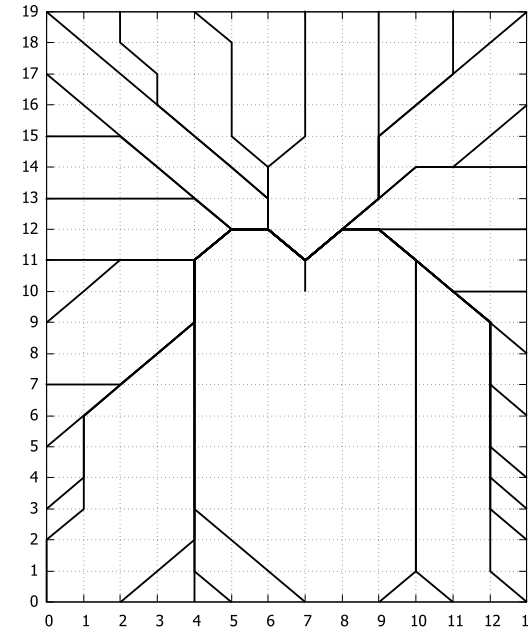
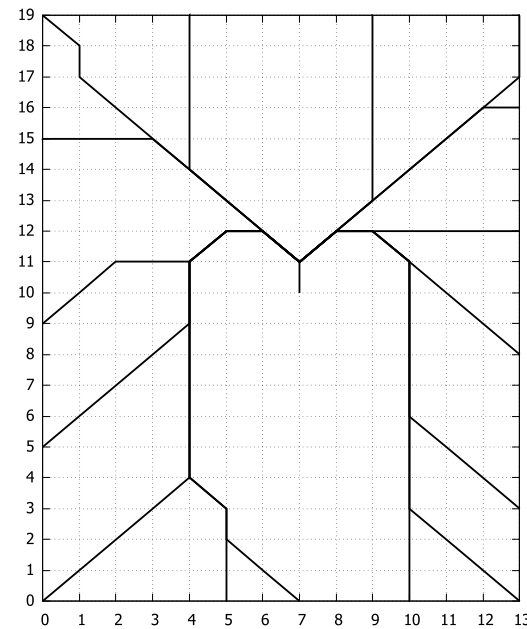
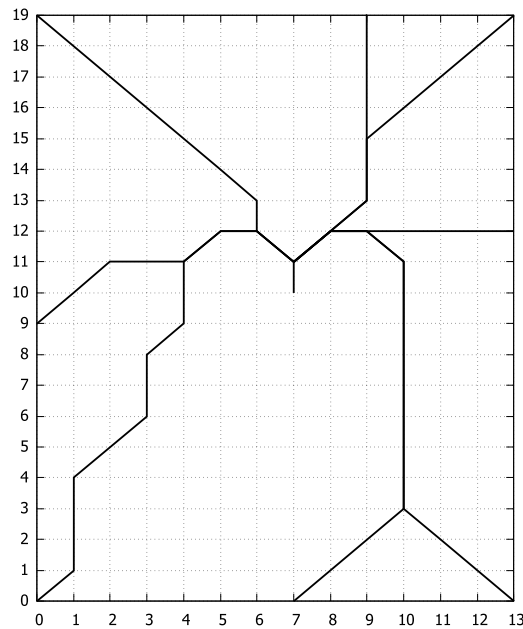
quite dense network
of routes →

tree weight



Increased Number of Entry Points:

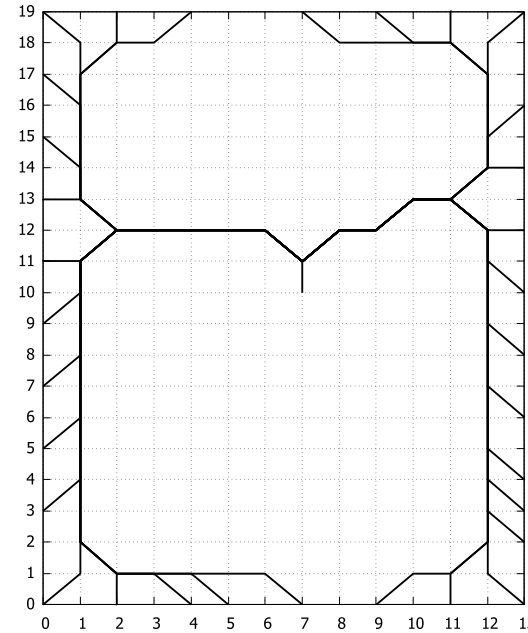
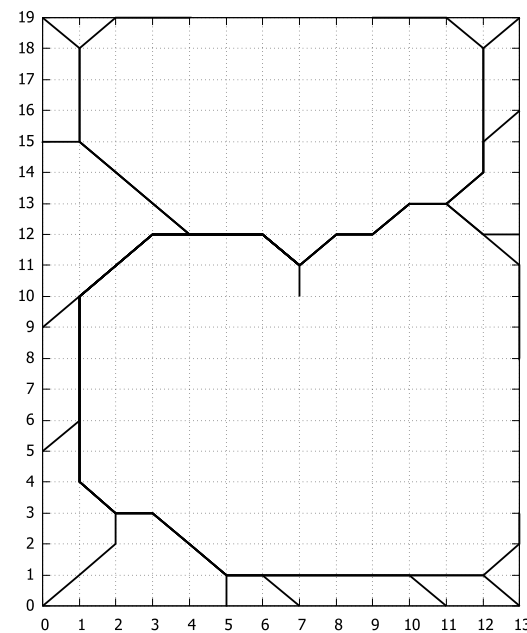
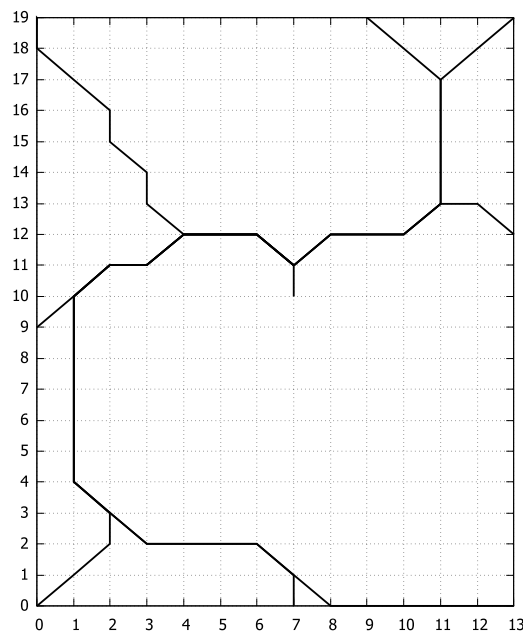
paths length



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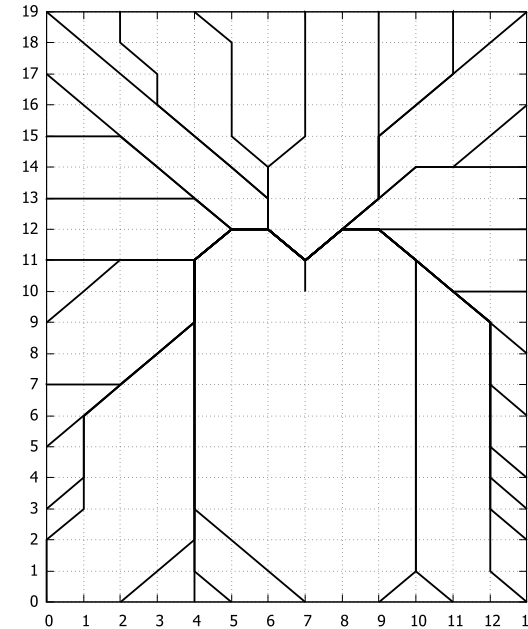
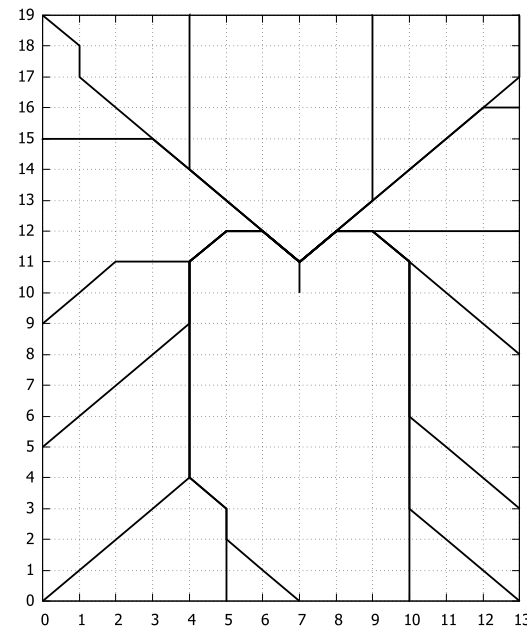
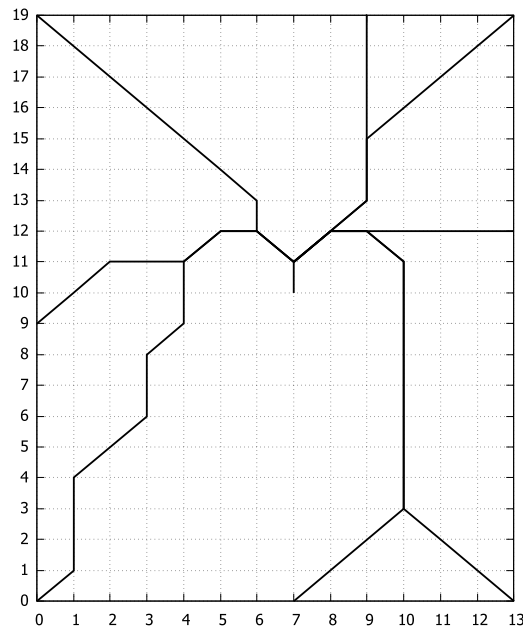
quite dense network
of routes →
hard to control the traffic

tree weight



Increased Number of Entry Points:

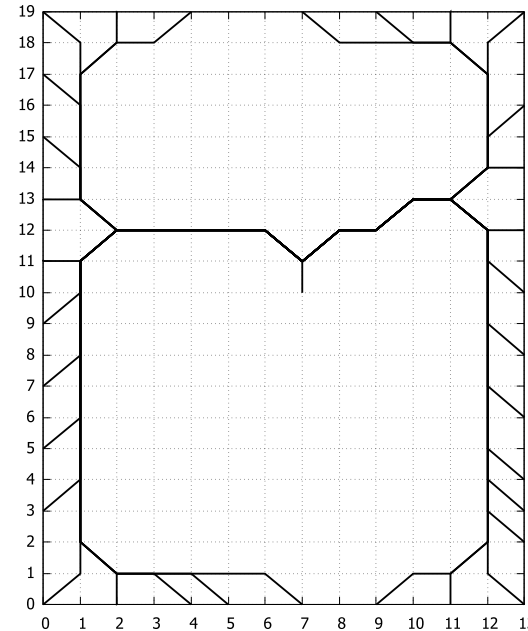
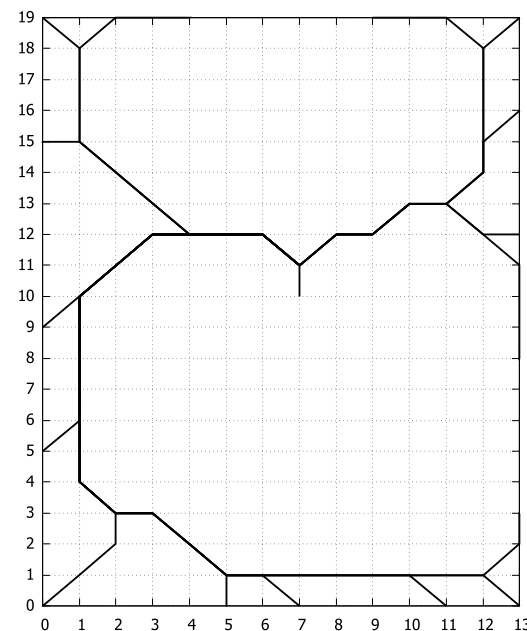
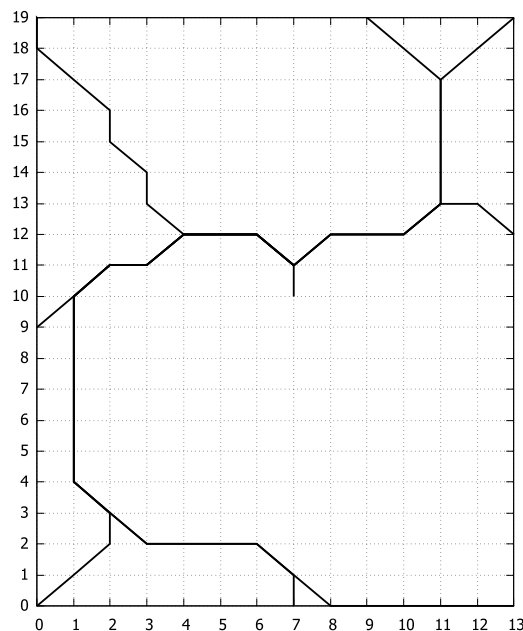
paths length



serve the airlines'
request for short
trajectories best

quite dense network
of routes →
hard to control the traffic

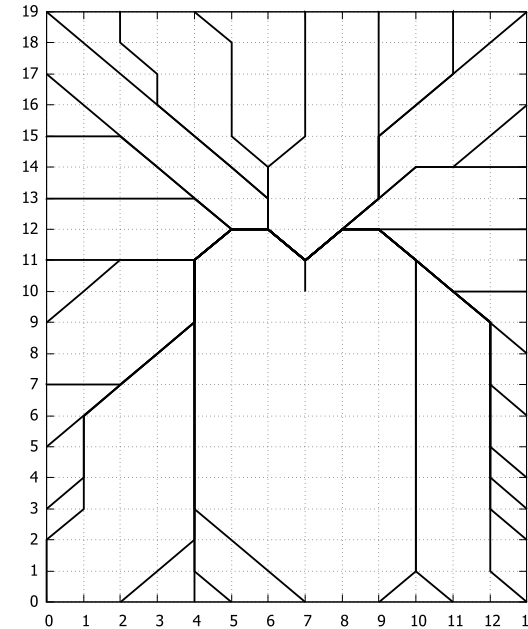
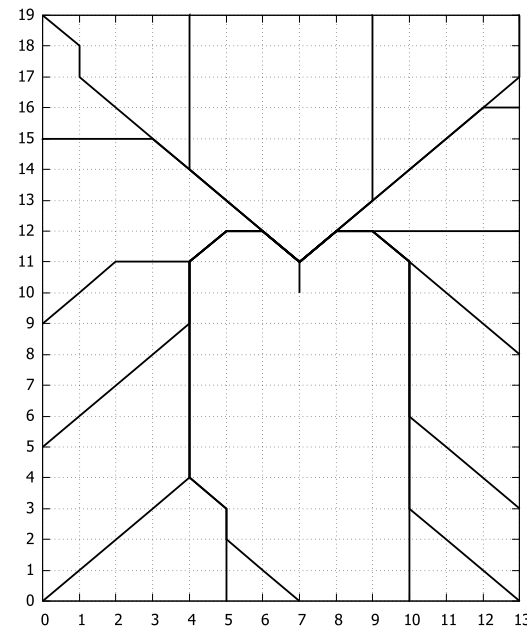
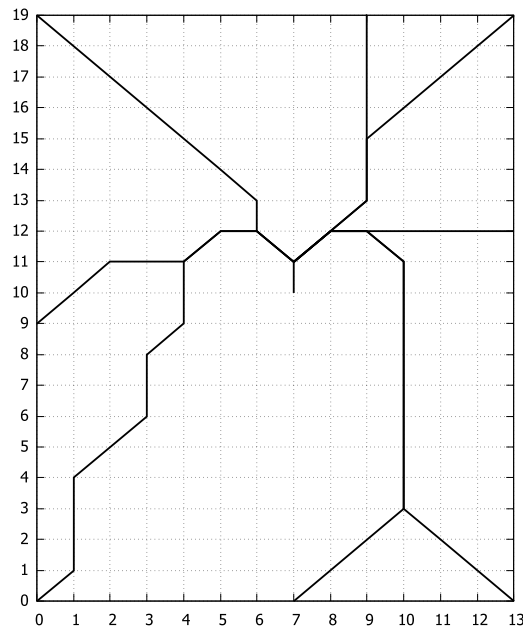
tree weight



most merge points are
located close to TMA
boundary

Increased Number of Entry Points:

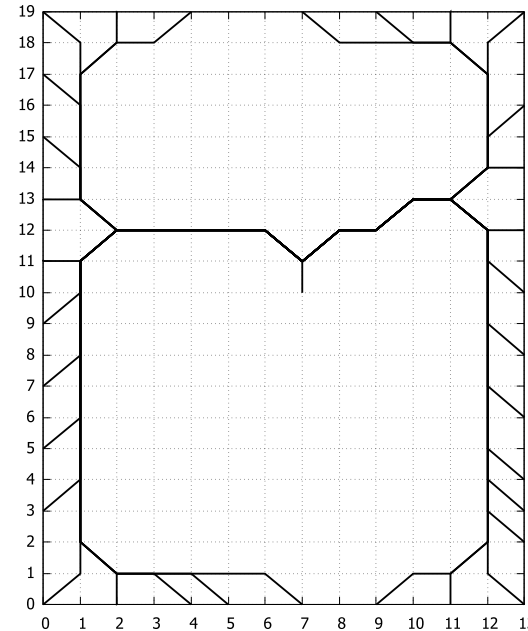
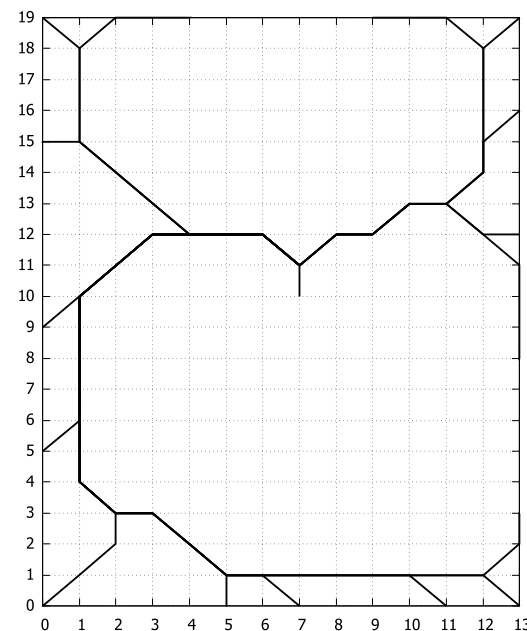
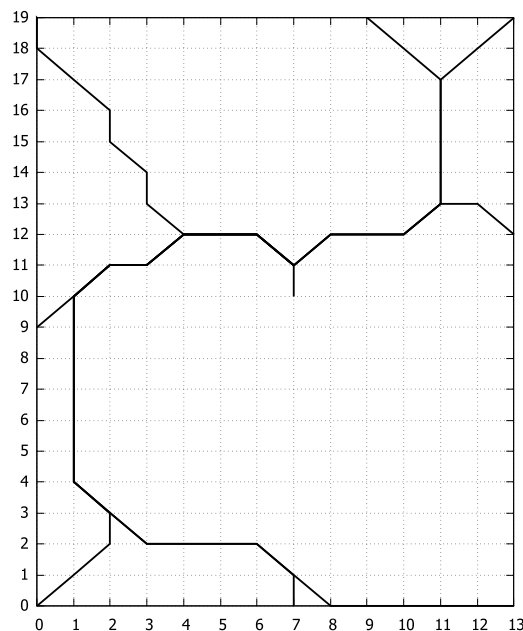
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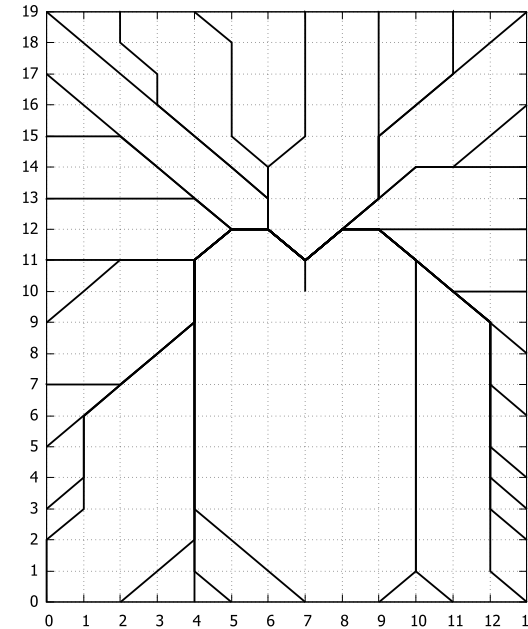
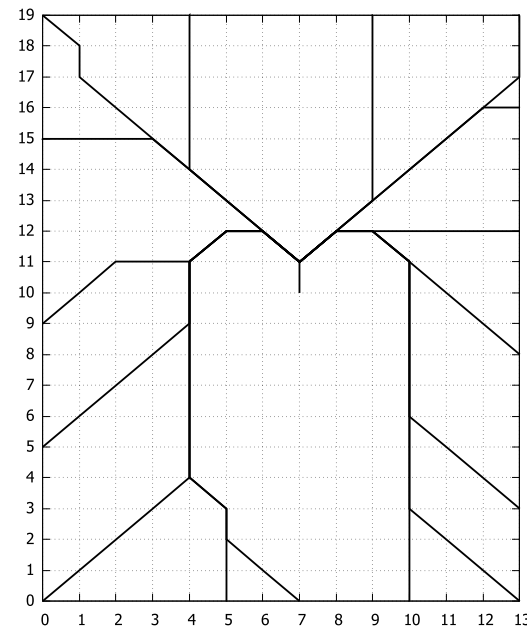
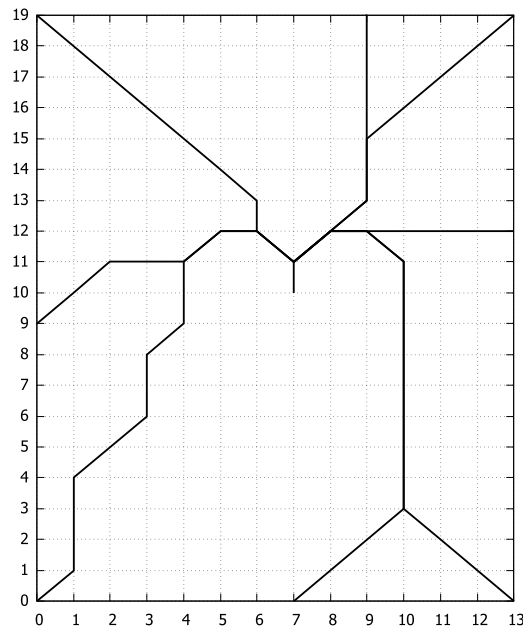


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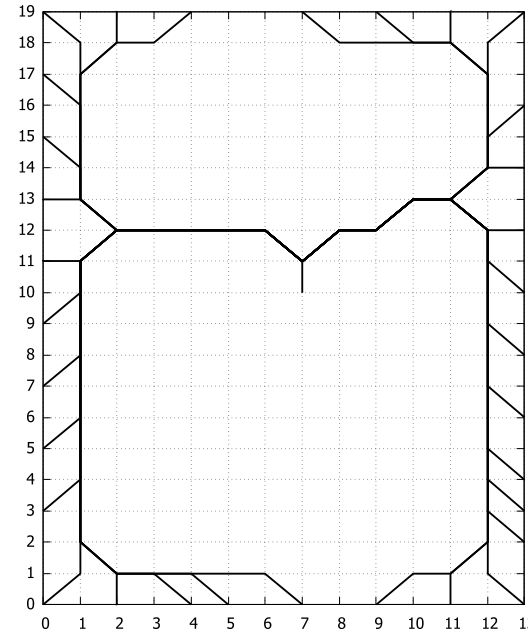
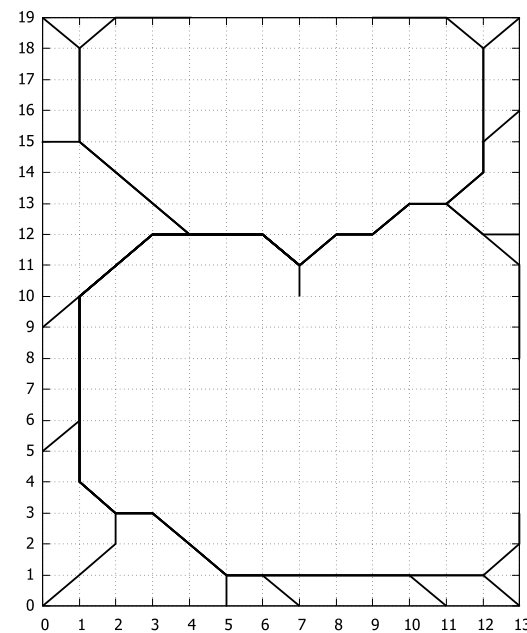
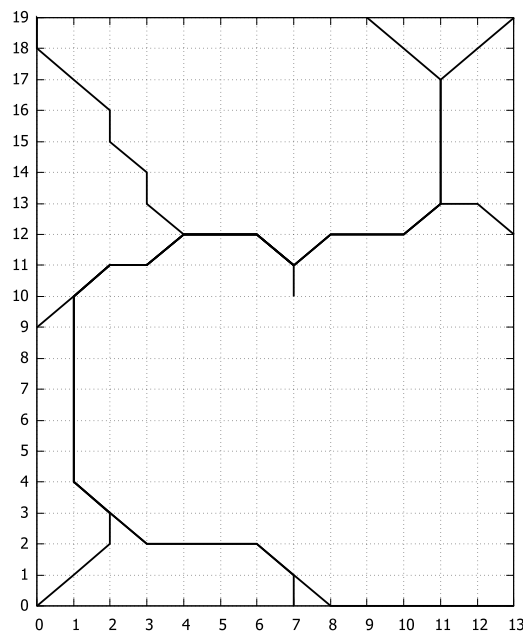
→ helpful to use linear combination of these two functions

Increased Number of Entry Points:

paths length



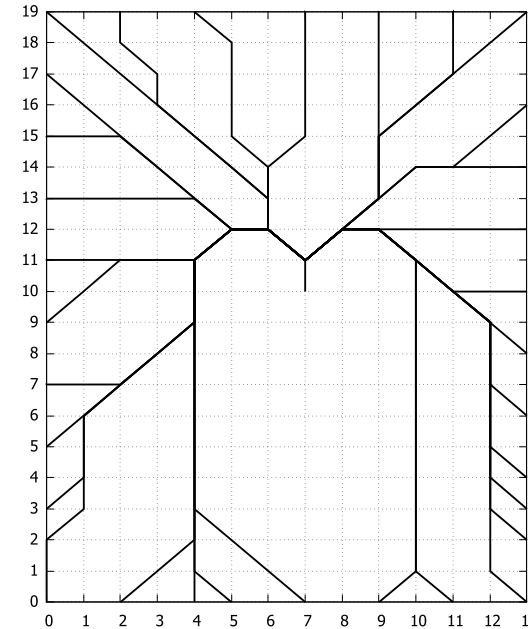
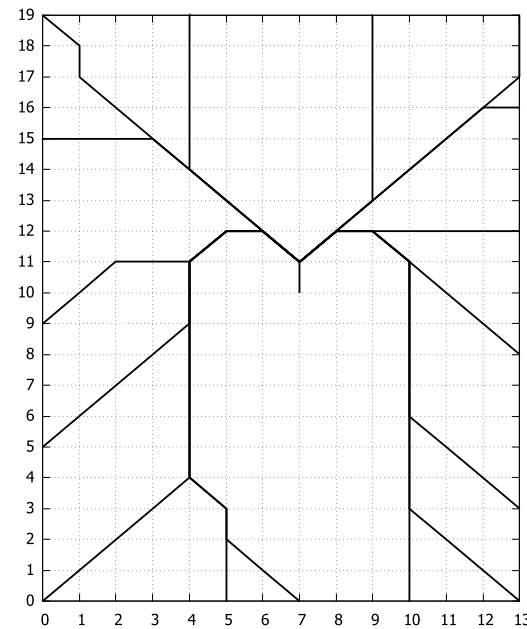
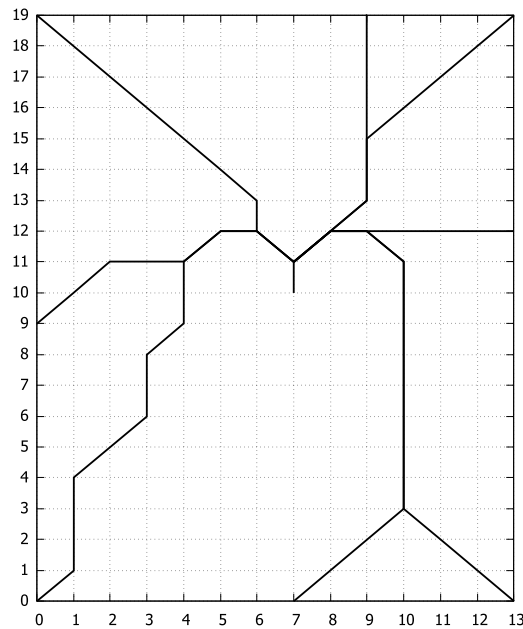
tree weight



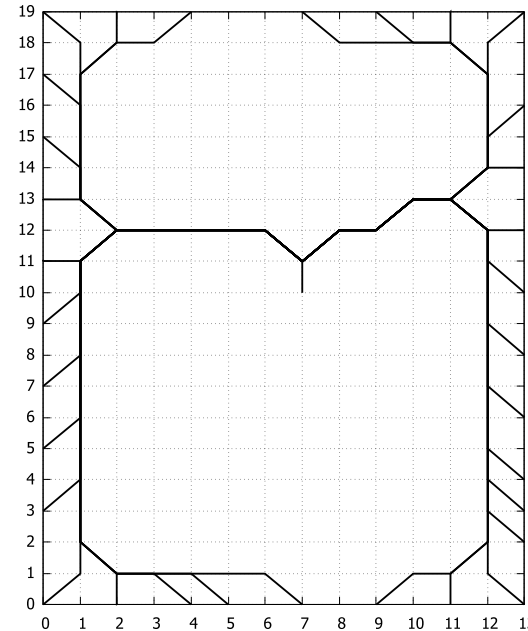
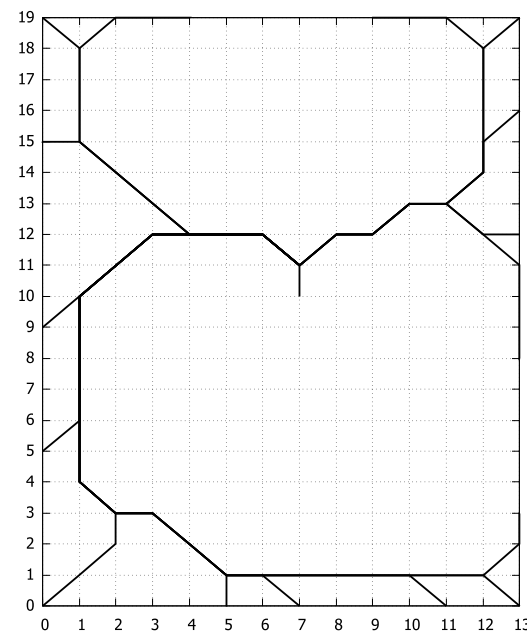
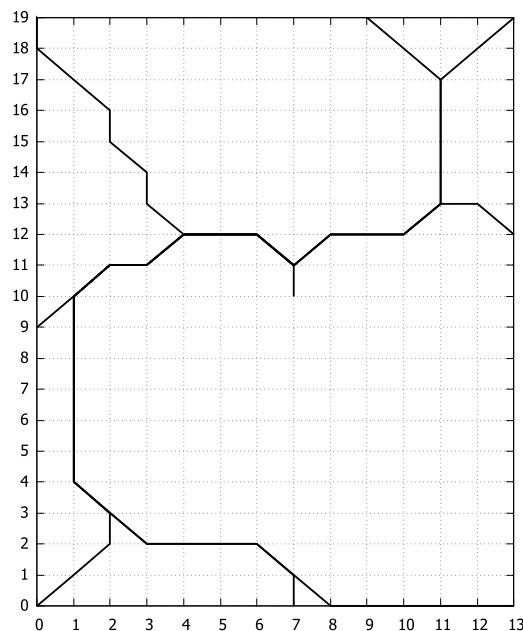
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Increased Number of Entry Points:

paths length



tree weight

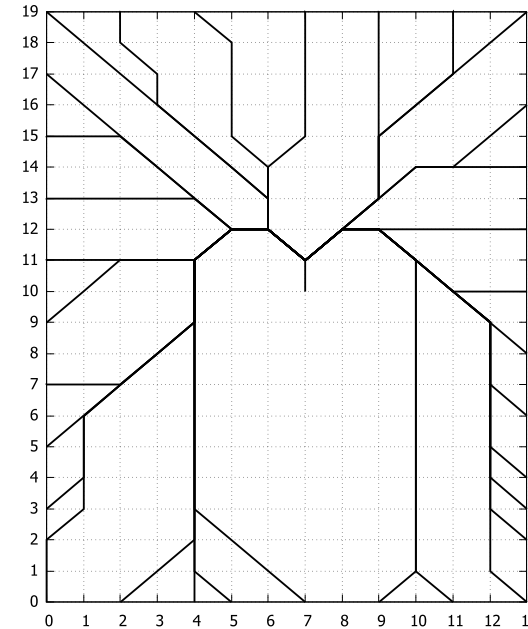
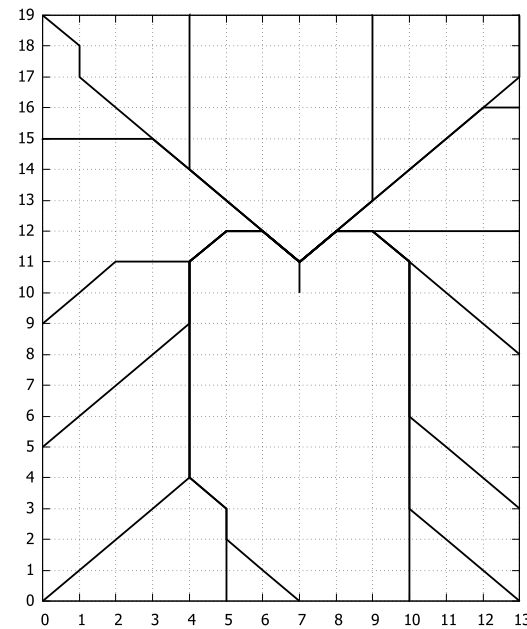
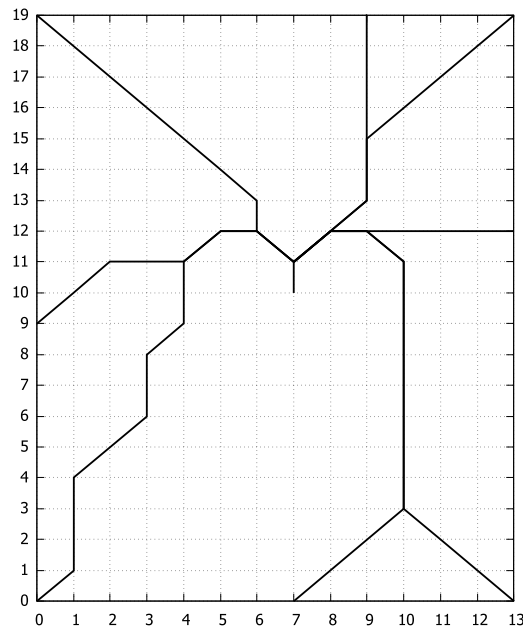


Solutions for large number of entry points could be used to suggest the number and location of entry points for a design from scratch.

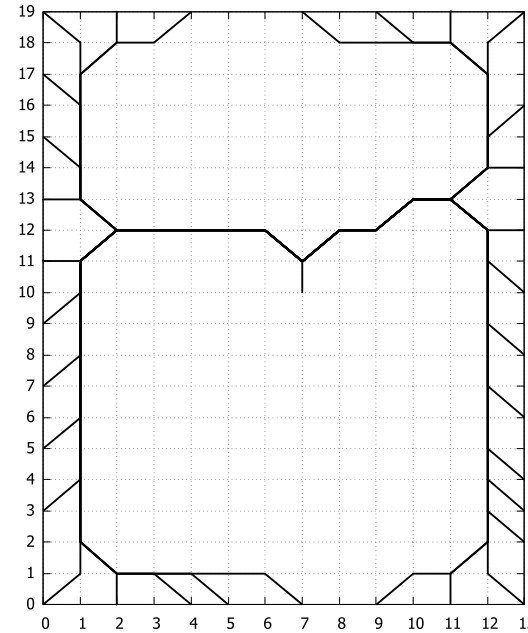
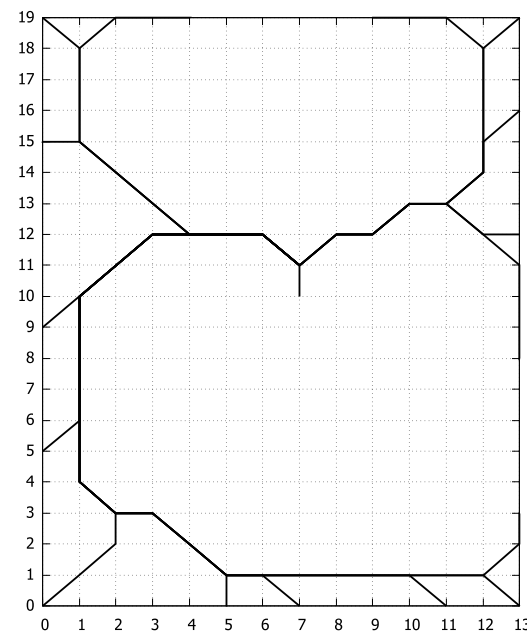
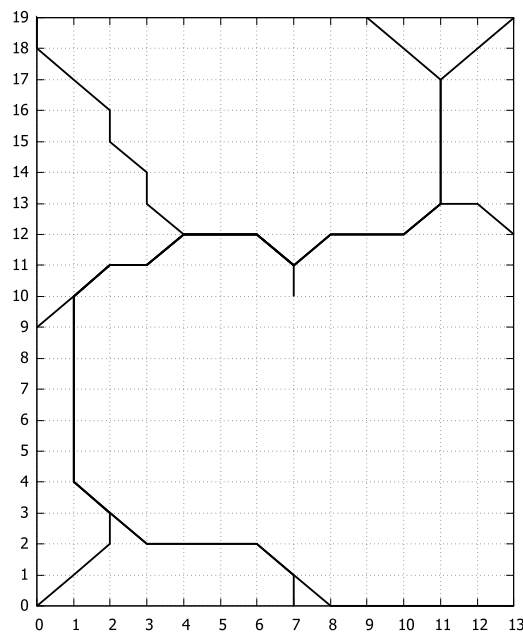
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Increased Number of Entry Points:

paths length



tree weight



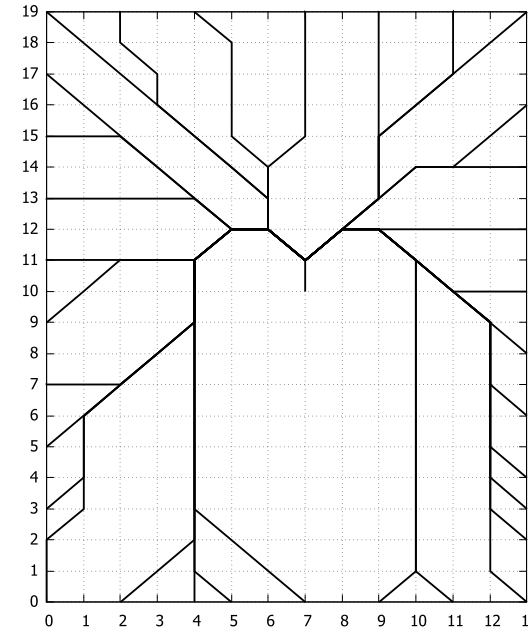
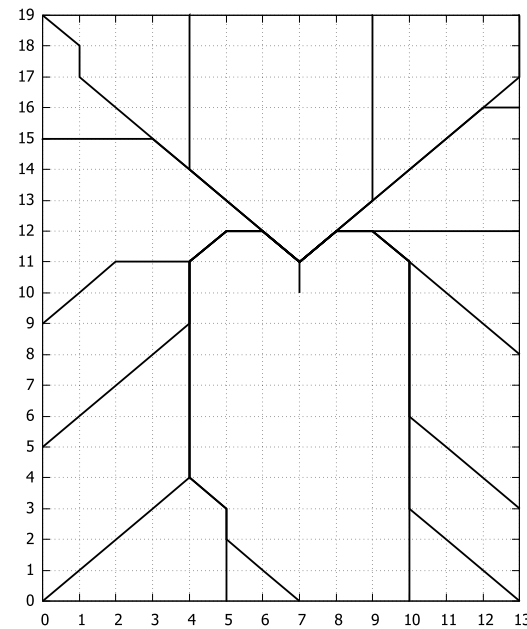
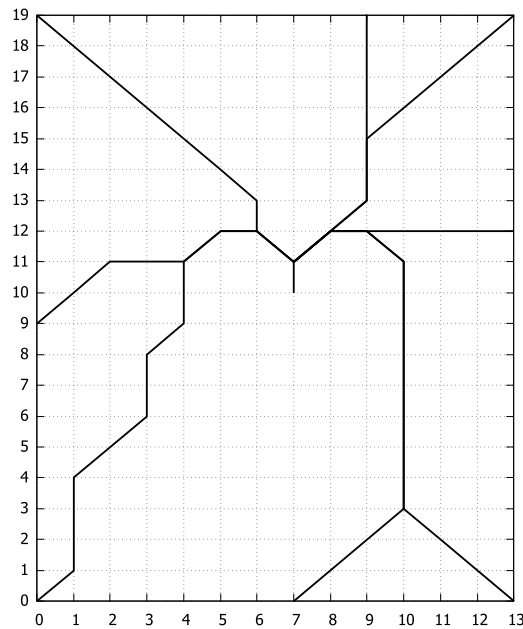
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2 entry points

→ helpful to use linear combination of these two functions

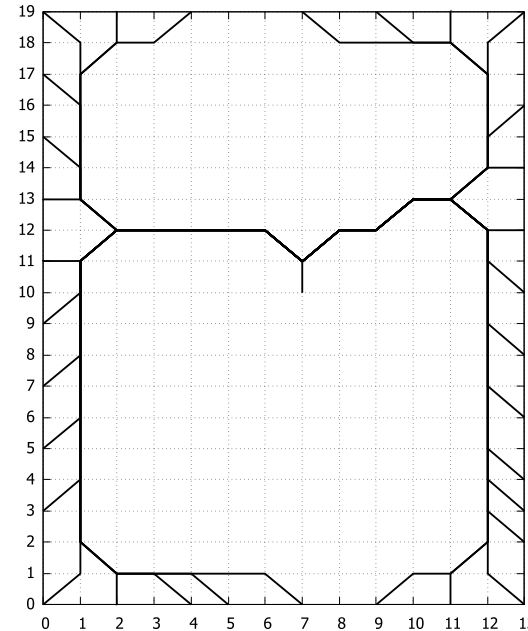
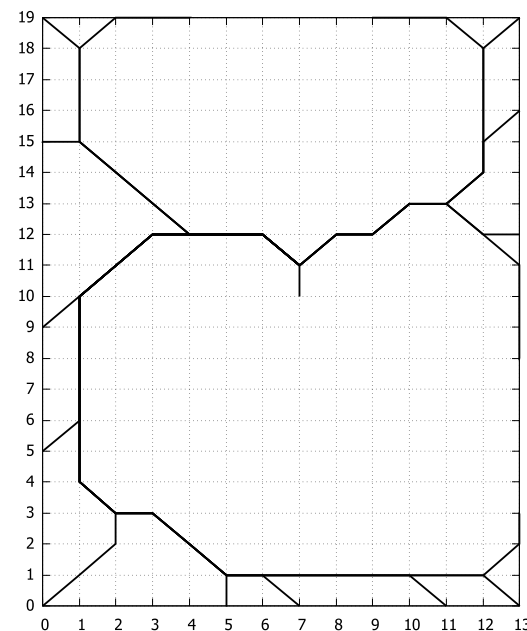
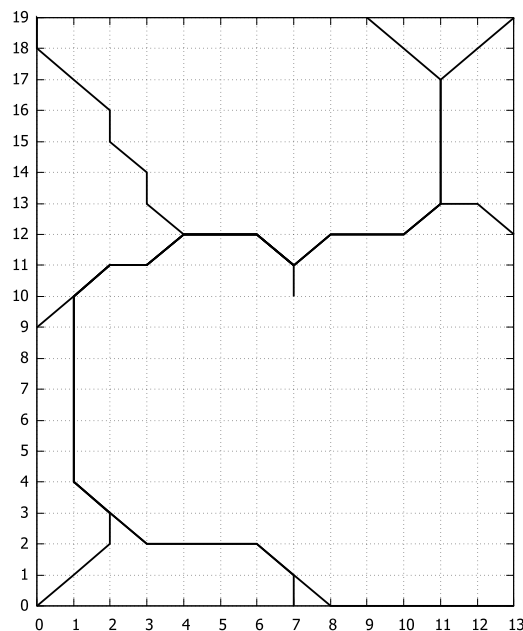
Increased Number of Entry Points:

paths length



16 entry points

tree weight

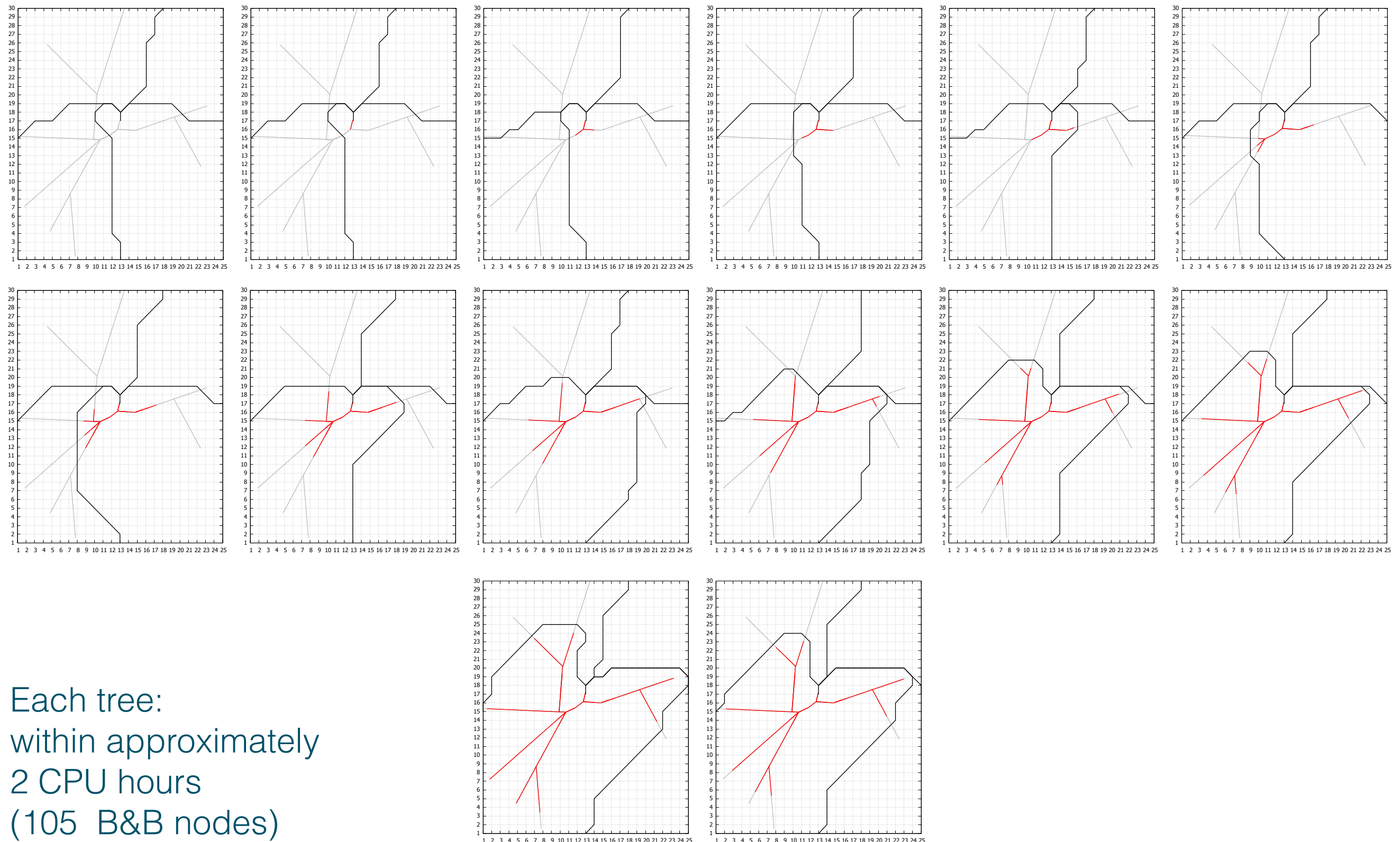


2 entry points

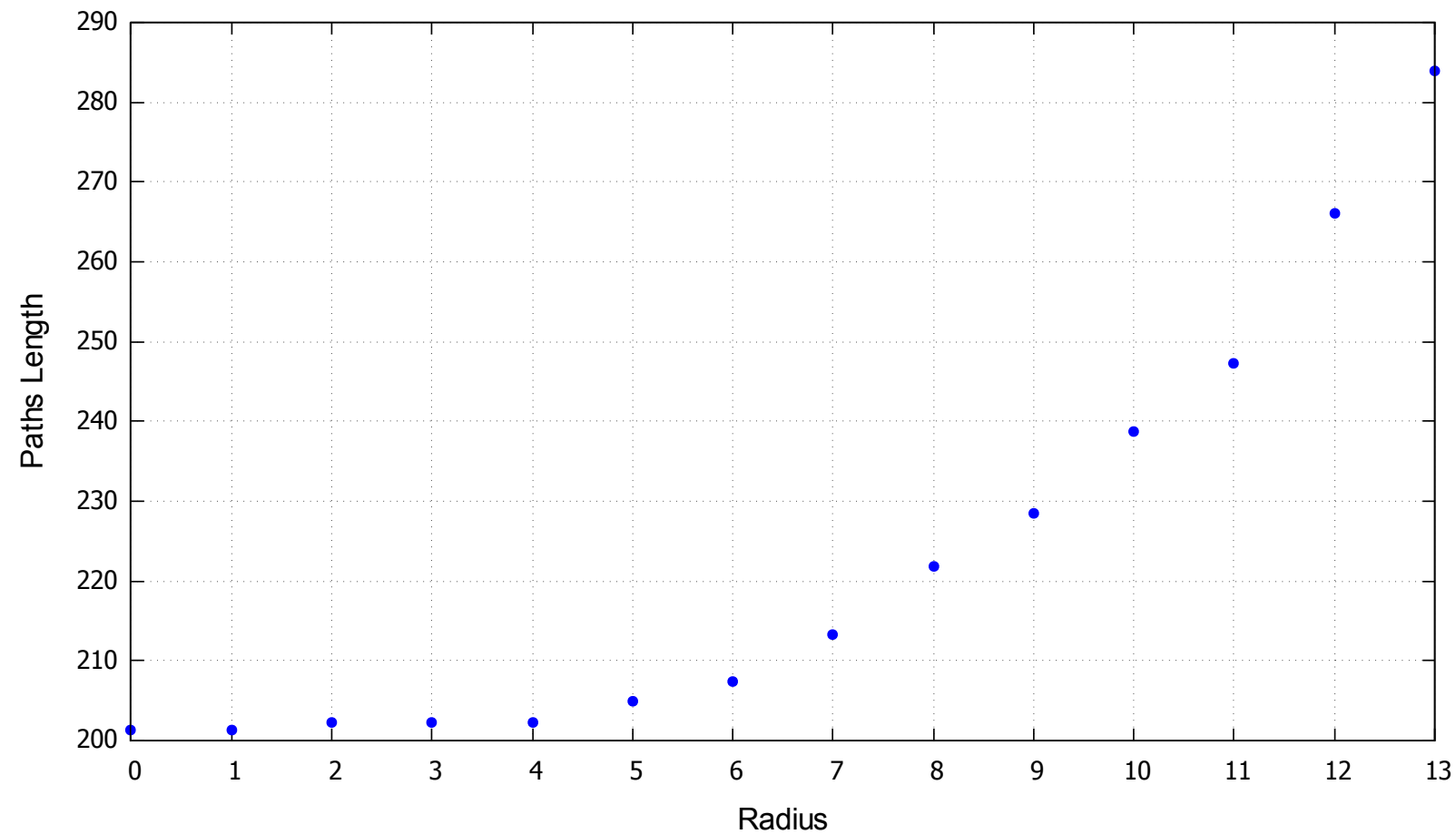
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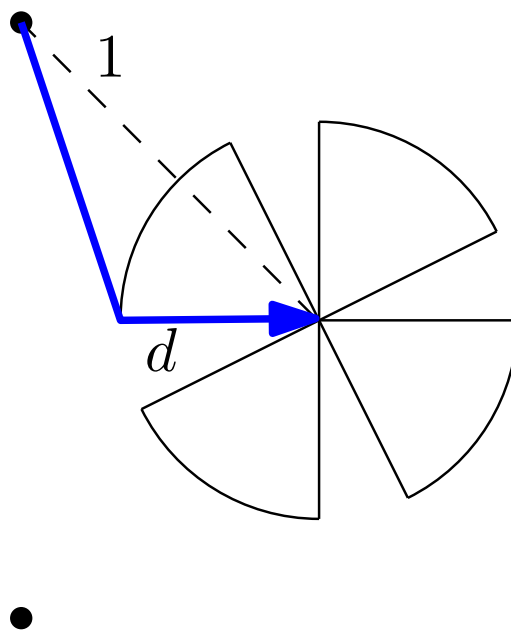
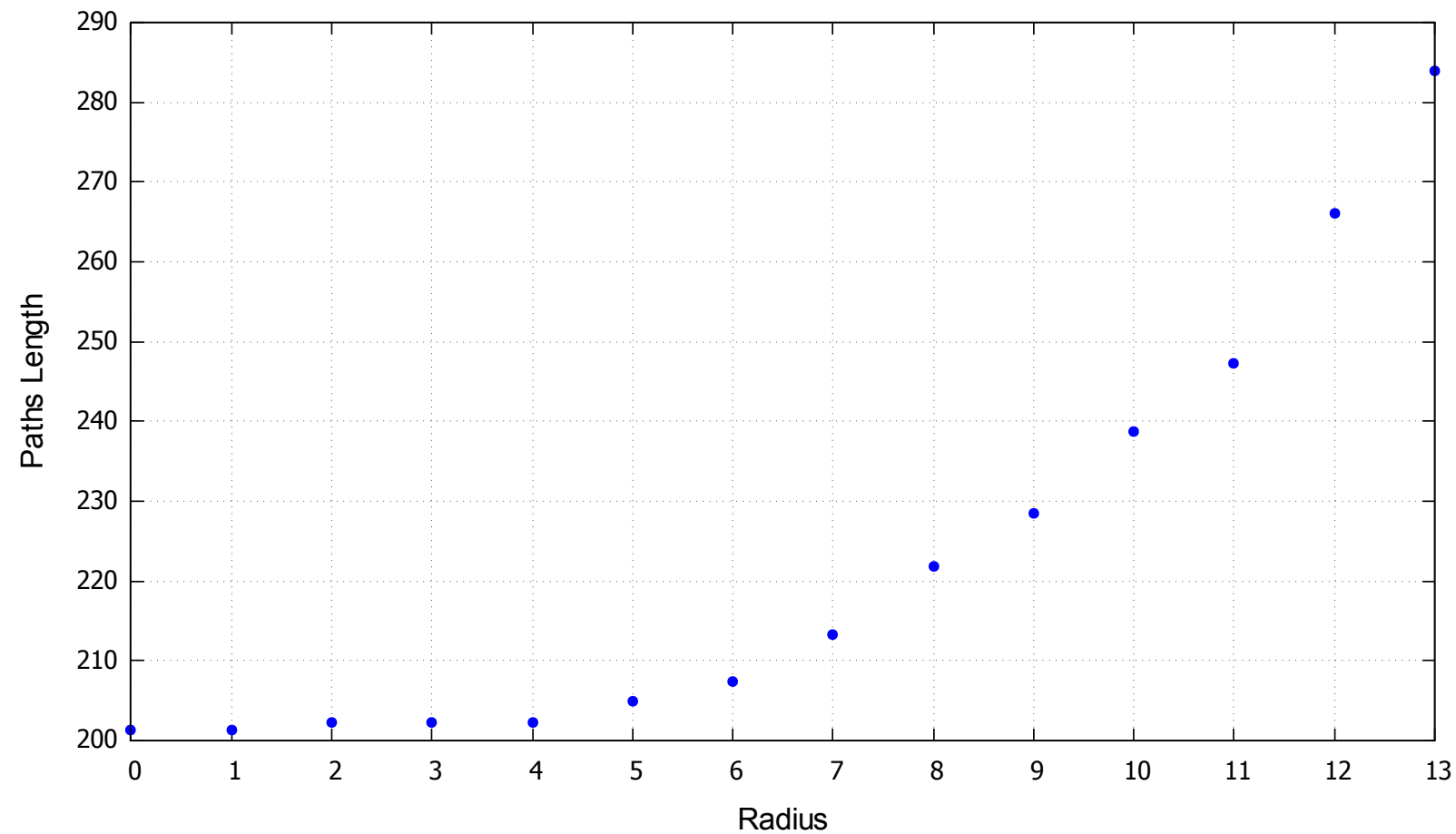
SID constraints:



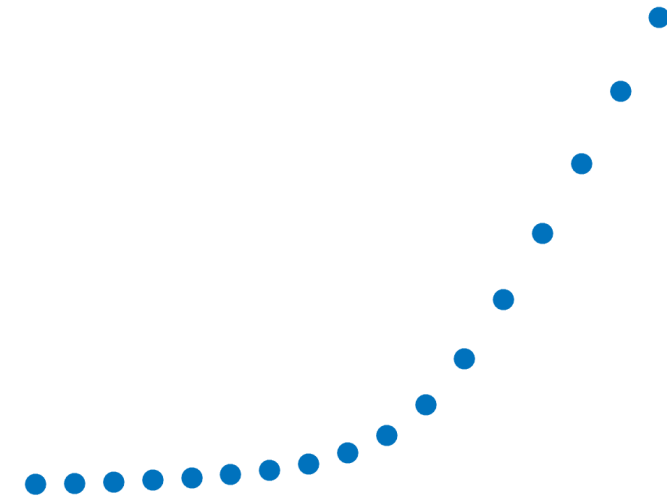
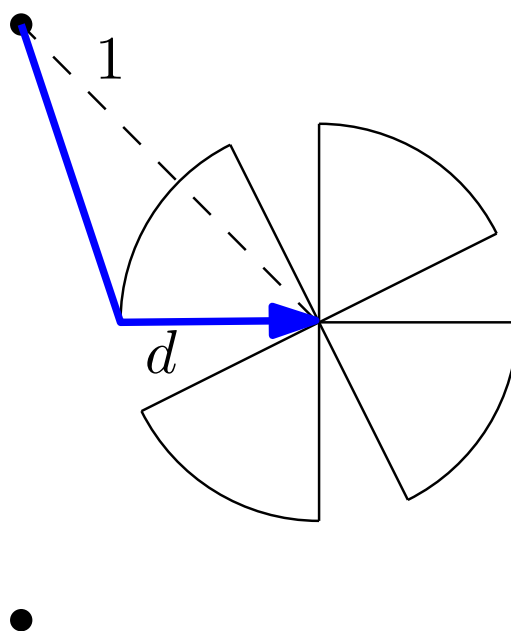
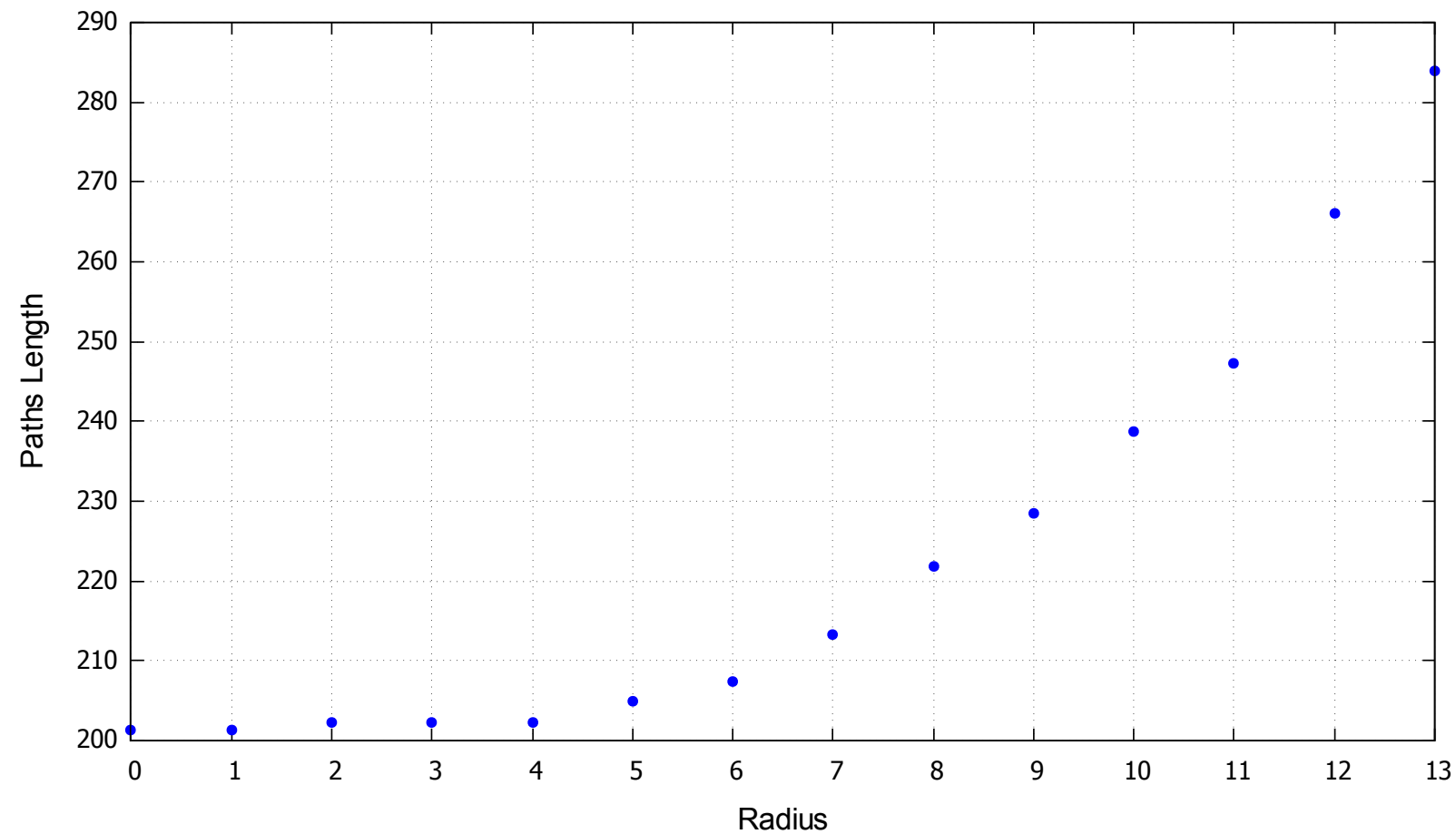
SID constraints:



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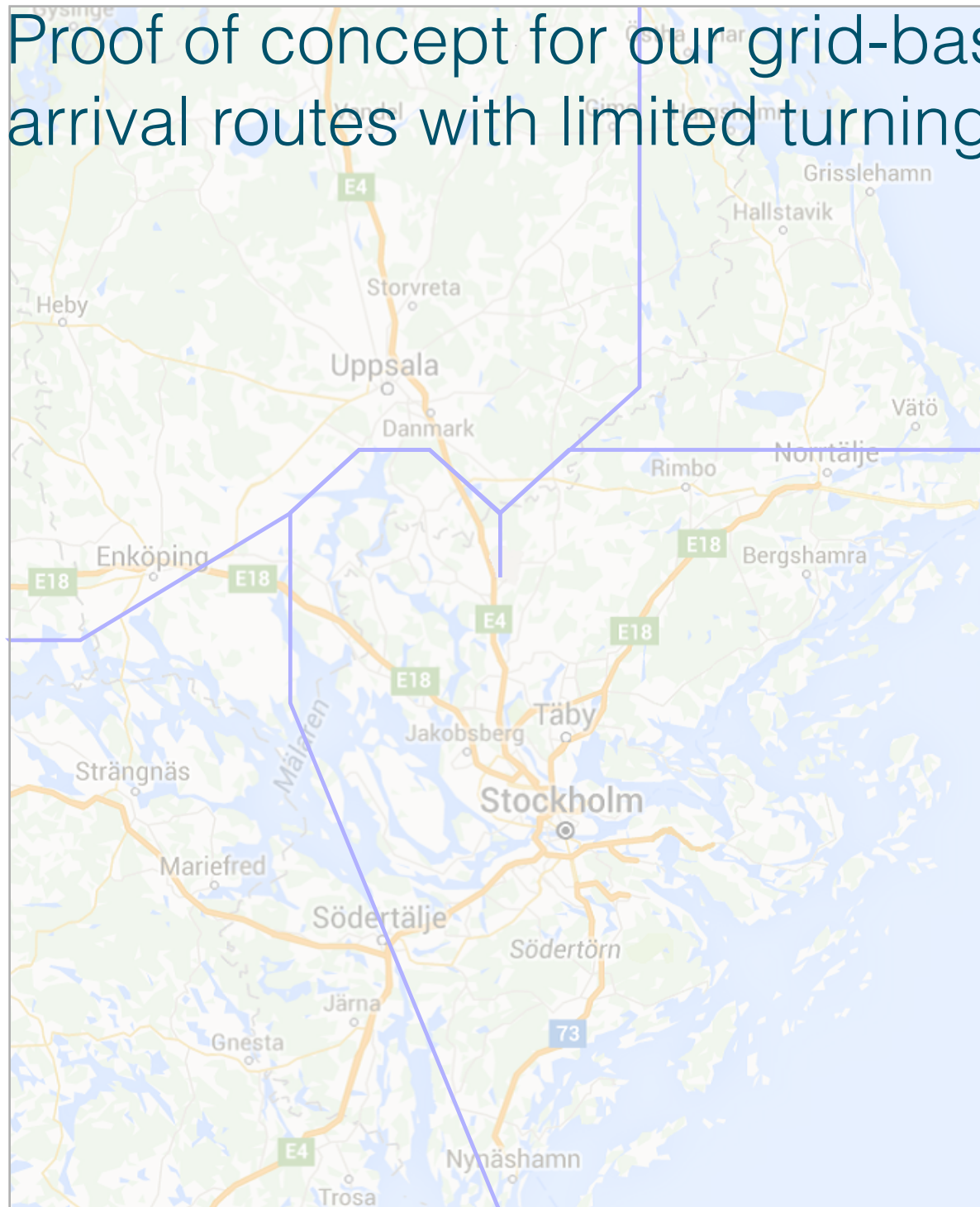
SID constraints:



Conclusion/Outlook

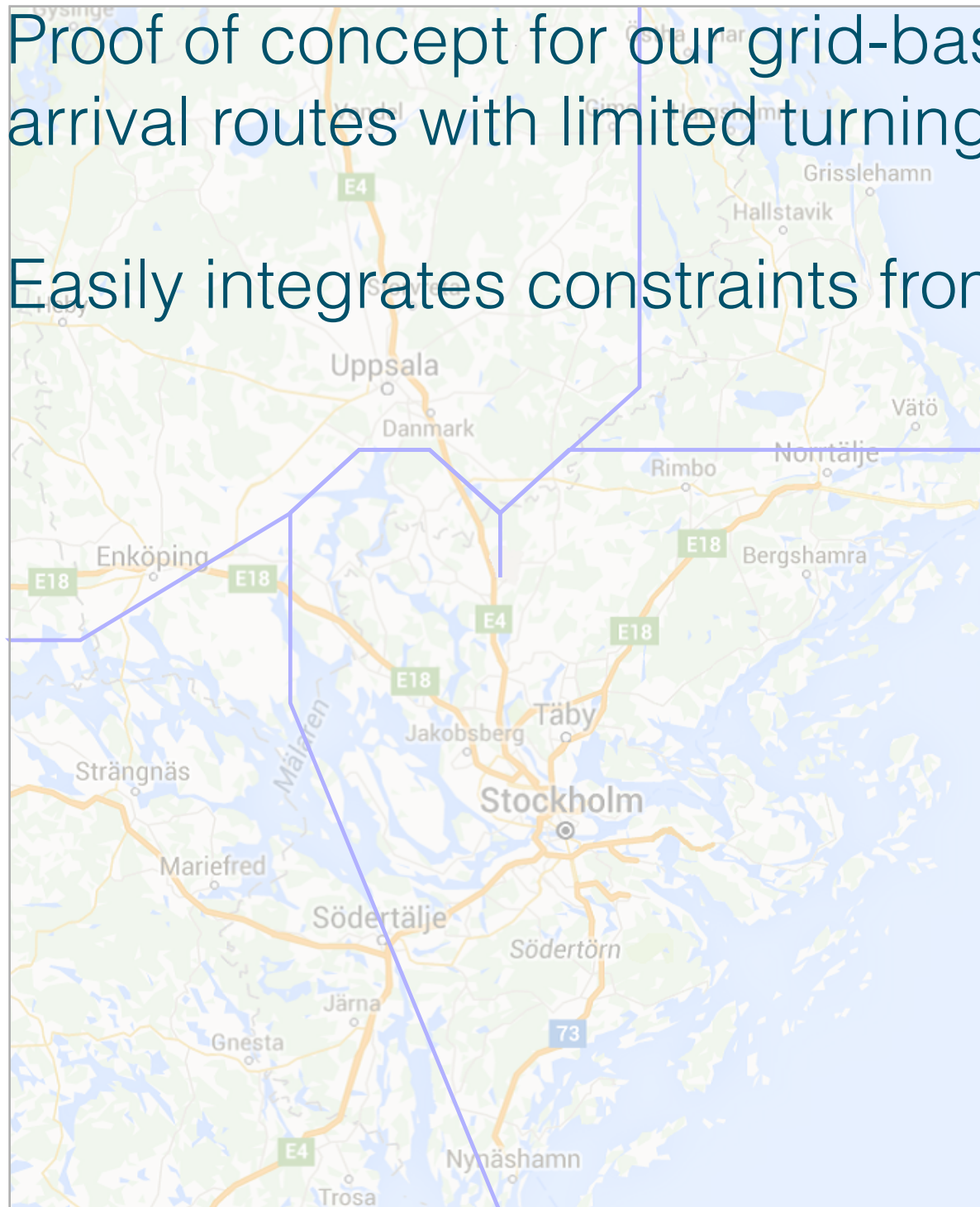


Proof of concept for our grid-based IP approach for finding aircraft arrival routes with limited turning angle



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

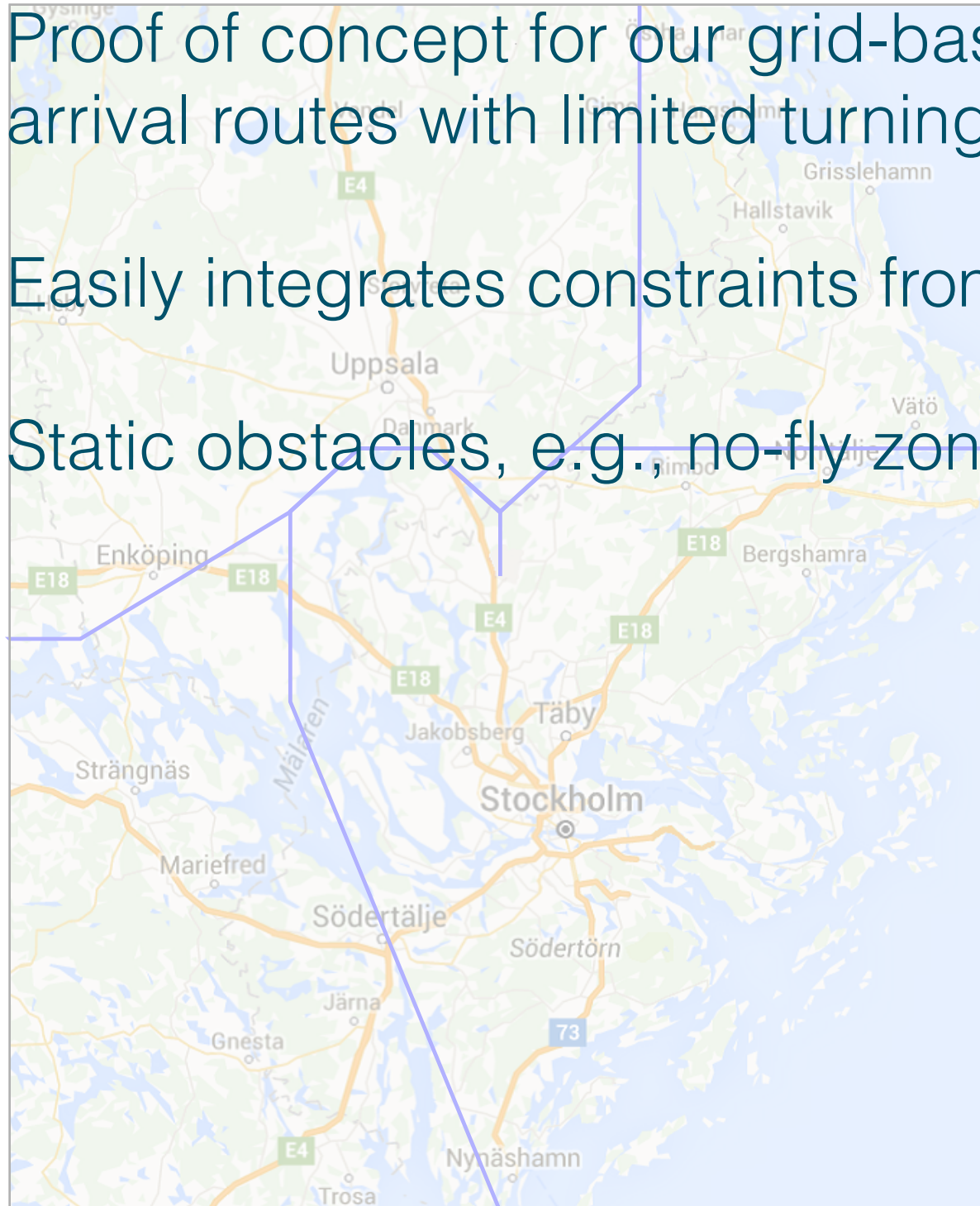
Easily integrates constraints from the departure routes



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

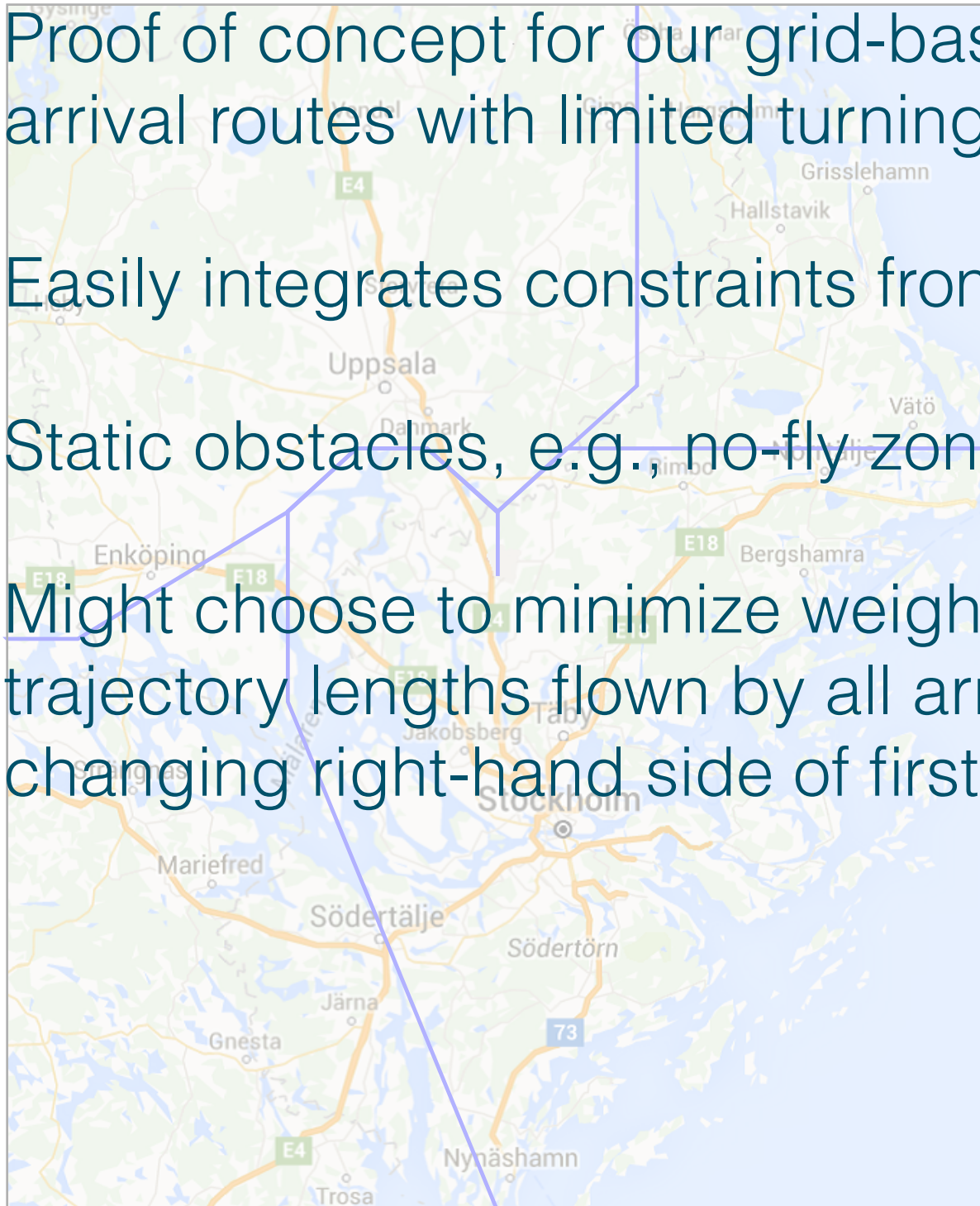


Proof of concept for our grid-based IP approach for finding aircraft arrival routes with limited turning angle

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)



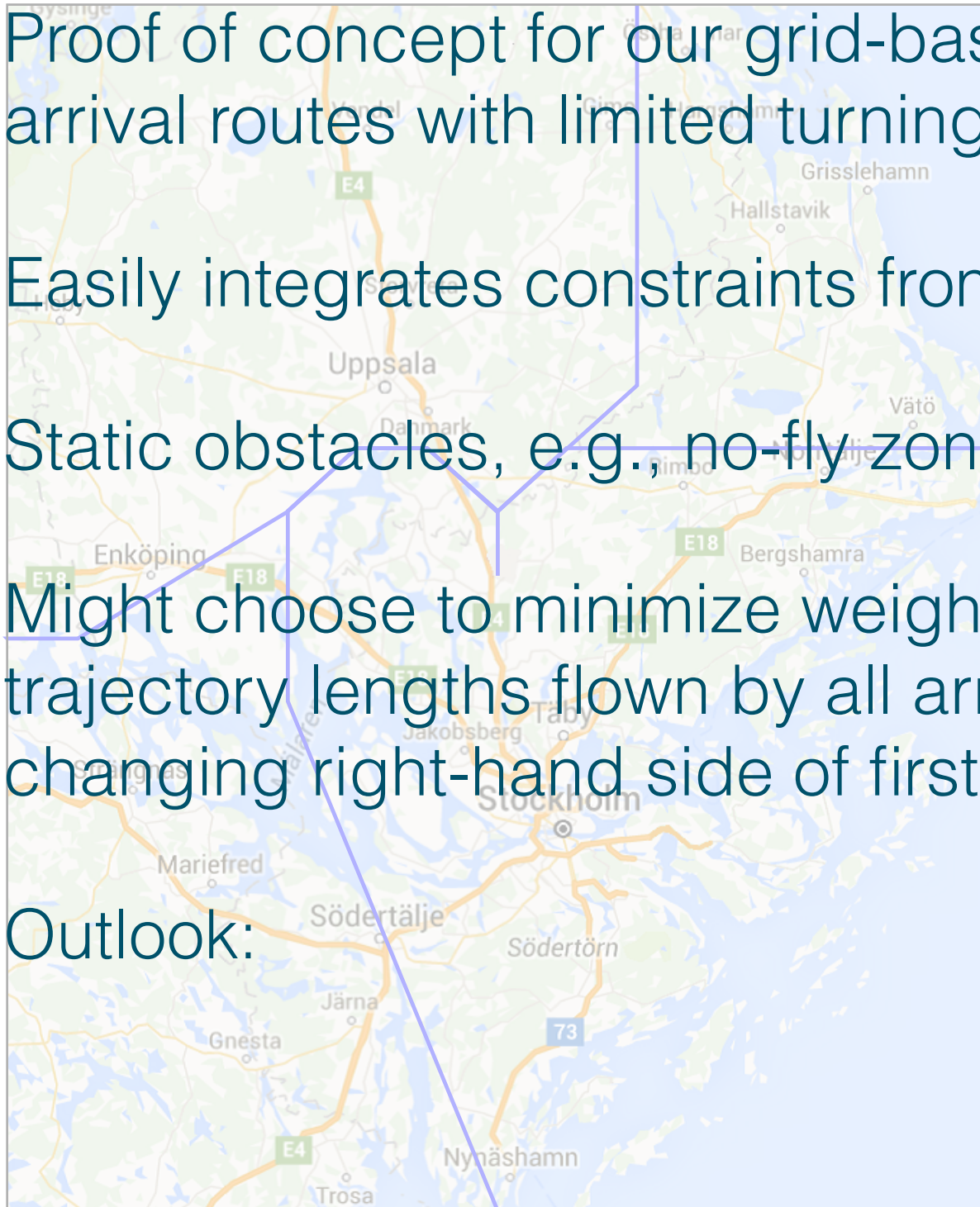
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Outlook:



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

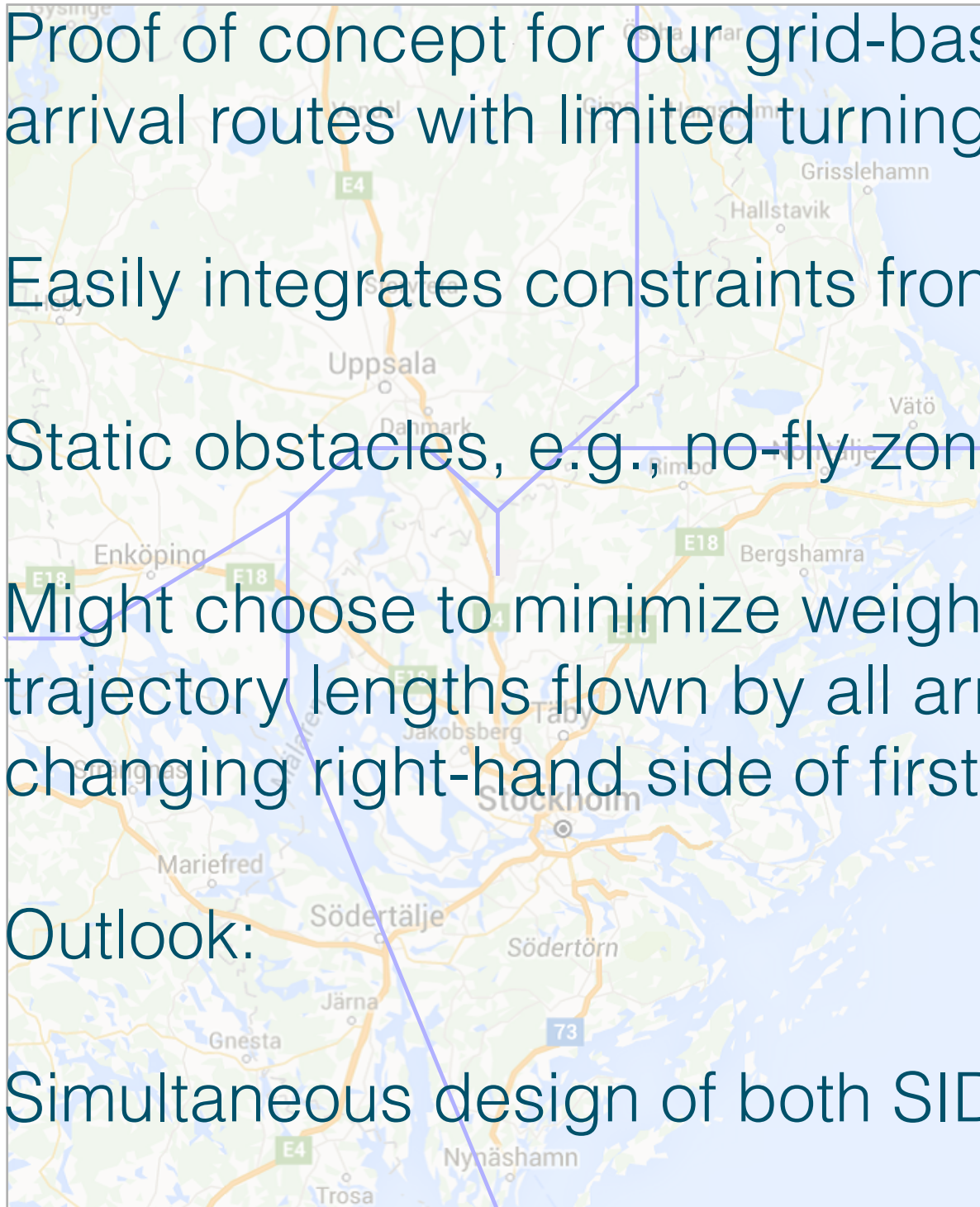
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Outlook:

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

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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

