

A Baseline for Terminal Airspace Design Assessment

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DK-
SE
FAB



DK
FIR
+
SE
FIR



Flights
on
Apr 30
2012



Flights
on
Apr 30
2013

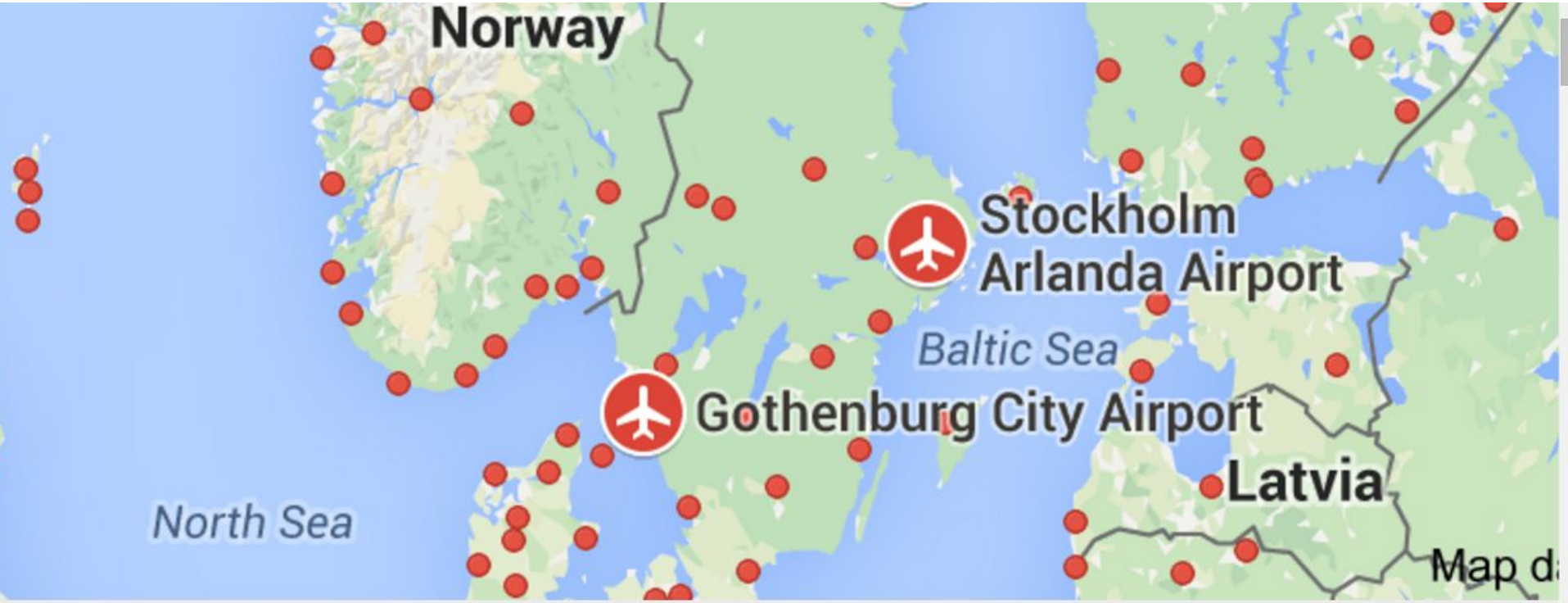


Congestion hotspots:

Airports

Sweden's 3 largest airports:

- Arlanda
- Gothenburg
- Bromma



Stockholm “Air Portal”

stockholm airports - Google

https://www.google.com/maps/search/stockholm+airports/@59.4577559,17.6755812,9z

stockholm airports

Rating
★★★★★

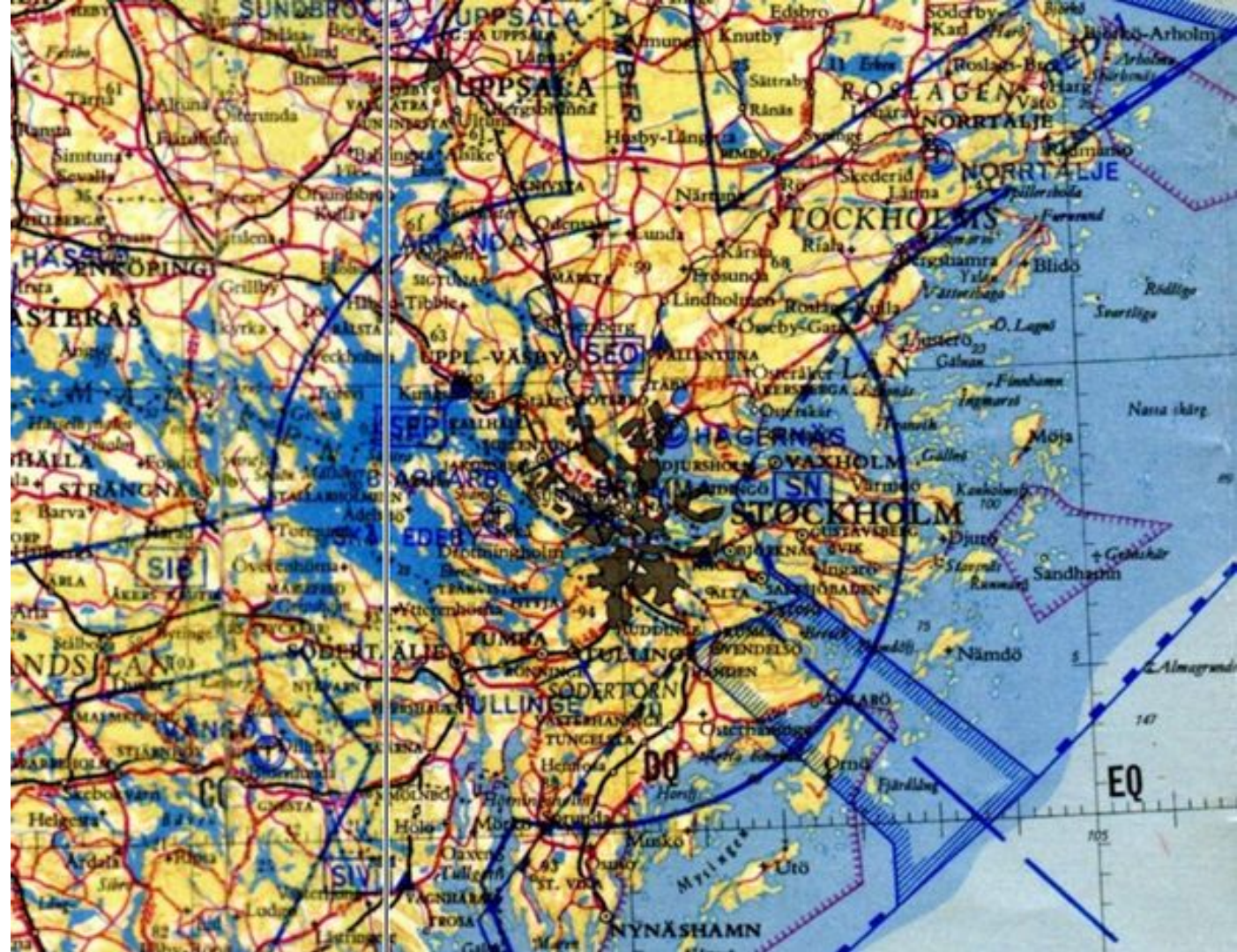
Bromma Stockholm Airport
3.8 ★★★★★ (58)
Airport · Ulvsundavägen
Transport hub serving Sweden's capital

Stockholm Arlanda Airport
4.0 ★★★★★ (461)
Airport
3-terminal airport & Scandinavian hub

Showing results 1 - 2

Map data ©2015 Google Terms Privacy maps.google.se

Stockholm TMA (1958)



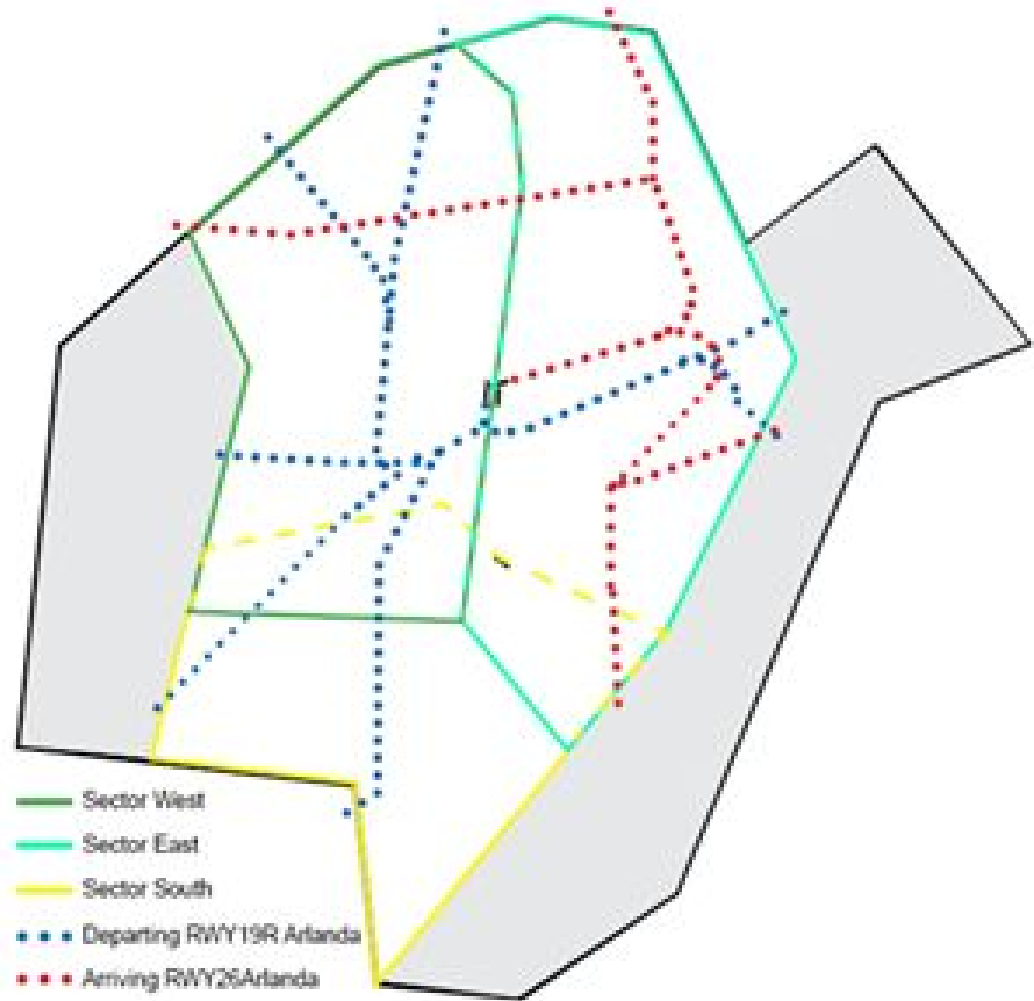
[Justusson, B. \(2015\).
Generalkarta 1958.
S.Sverige. flygversion](#)

Stockholm TMA (now)

1990's --

Historical layout

- Experts opinion
- Hands-on patching
- Rule-of-thumb
- No global outlook





Linköping University

ODESTA Project



AIR NAVIGATION SERVICES OF SWEDEN

- Optimal DESign of Terminal Airspace
- Linköping University
+LFV
+ reference group
- Funding for 2015--2018
 - Swedish Gov. Agency for Innovation Systems



EUROCONTROL



TRANSPORT
STYRELSEN



TRAFIKVERKET



swedavia
SWEDISH AIRPORTS

The logo for Vinnova, featuring the word "VINNOVA" in white capital letters on a green background with a wavy white line at the bottom.

VINNOVA

This talk

- (One possible) step towards operations optimization
 - single aspect
- Feeders $\leftrightarrow$ entry/exit points assignment
 - capacitated matching
 - different paradigms

Why such a study?

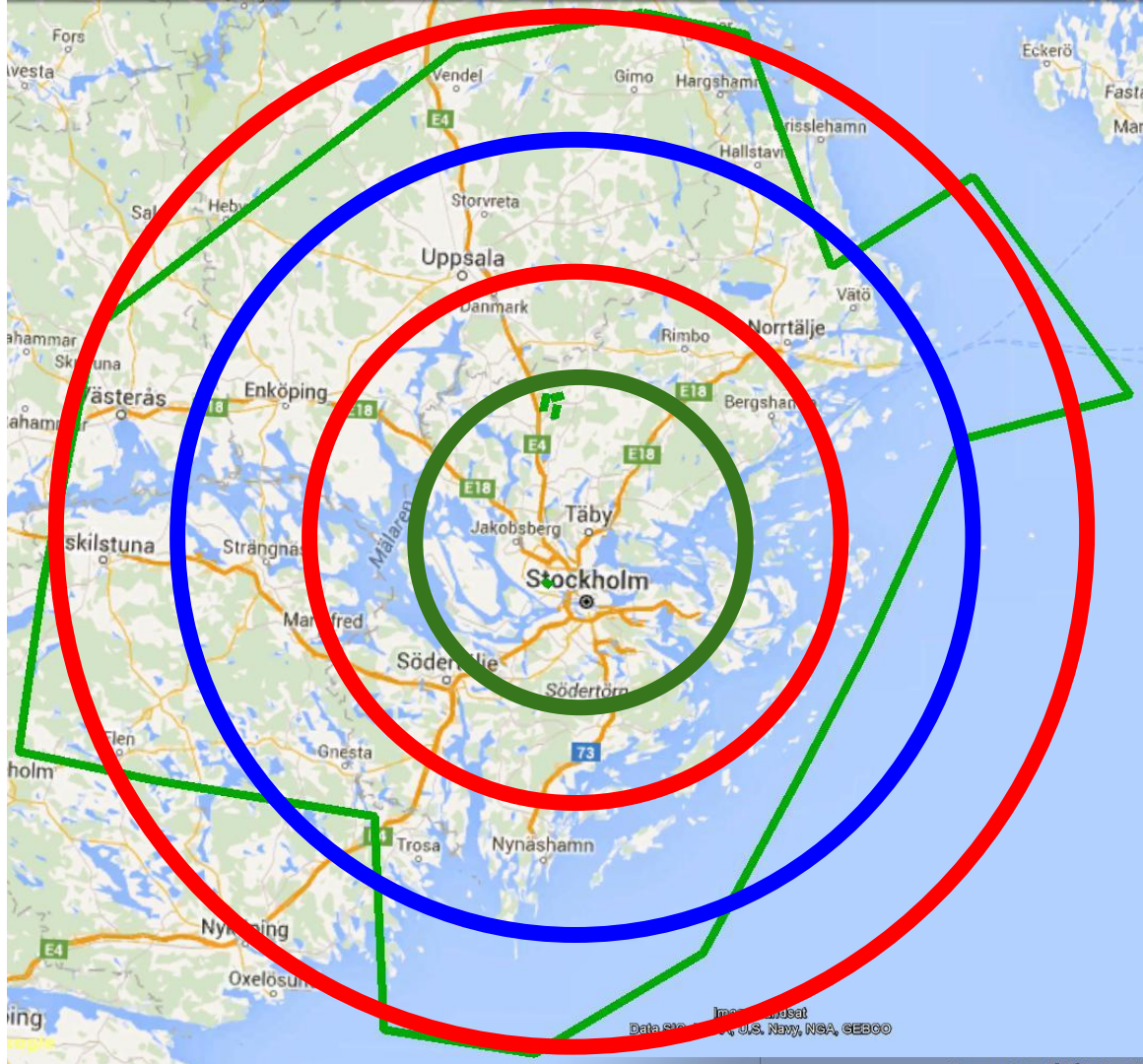
HUGE

optimization problem

How to deal?

Split into

- subproblems
- components
- layers
- ...



TMA design

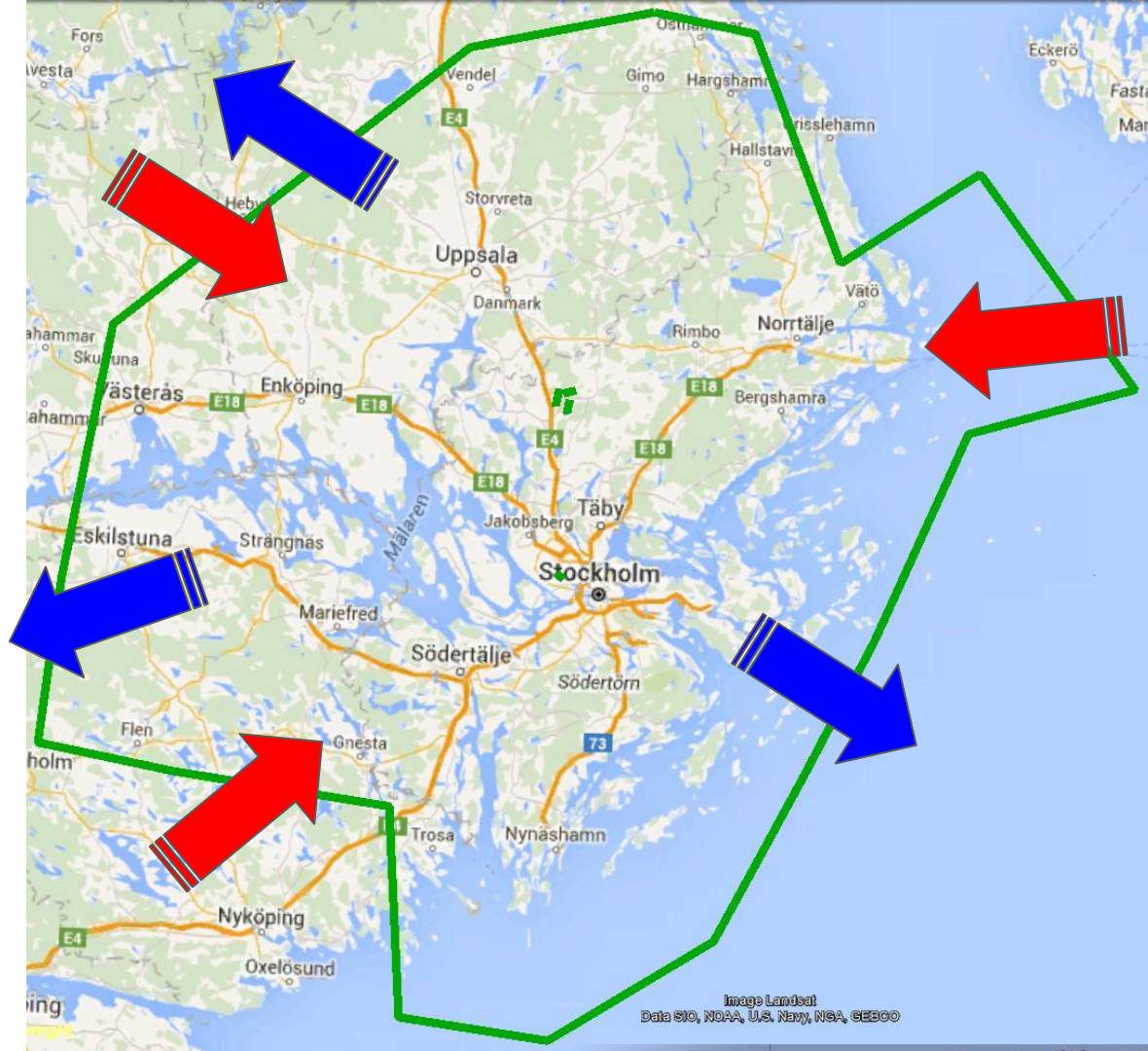
Matching

- demand
 - arrivals
 - departures

to

- resources
 - available airspace
 - RWYs

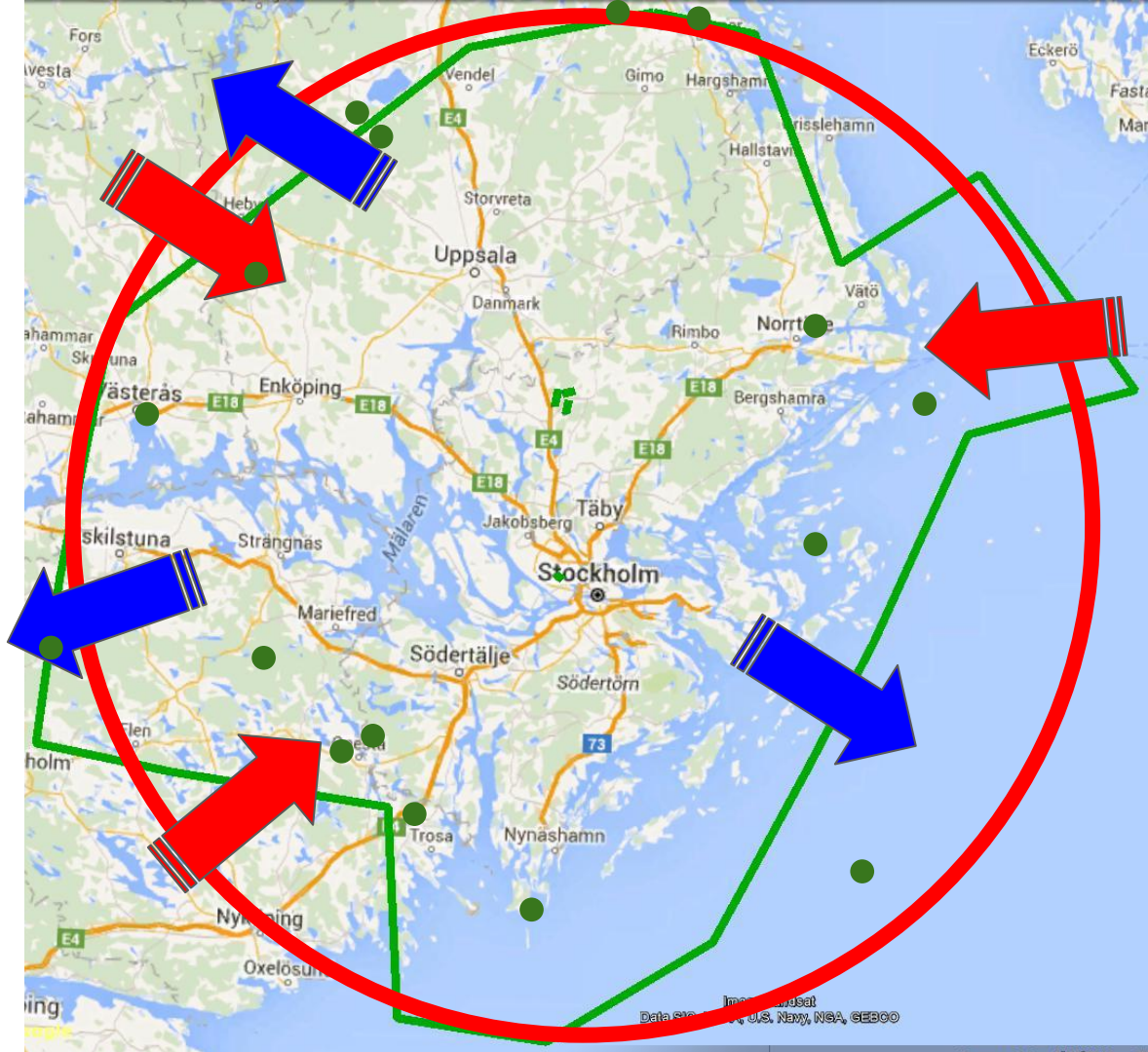
(with help of middleware)
STARS, SIDs, sectors, ...



Our focus

Outer rim

- demand
 - arrivals
 - departures
- resources
 - entry/exit points
 - considered **fixed, given**



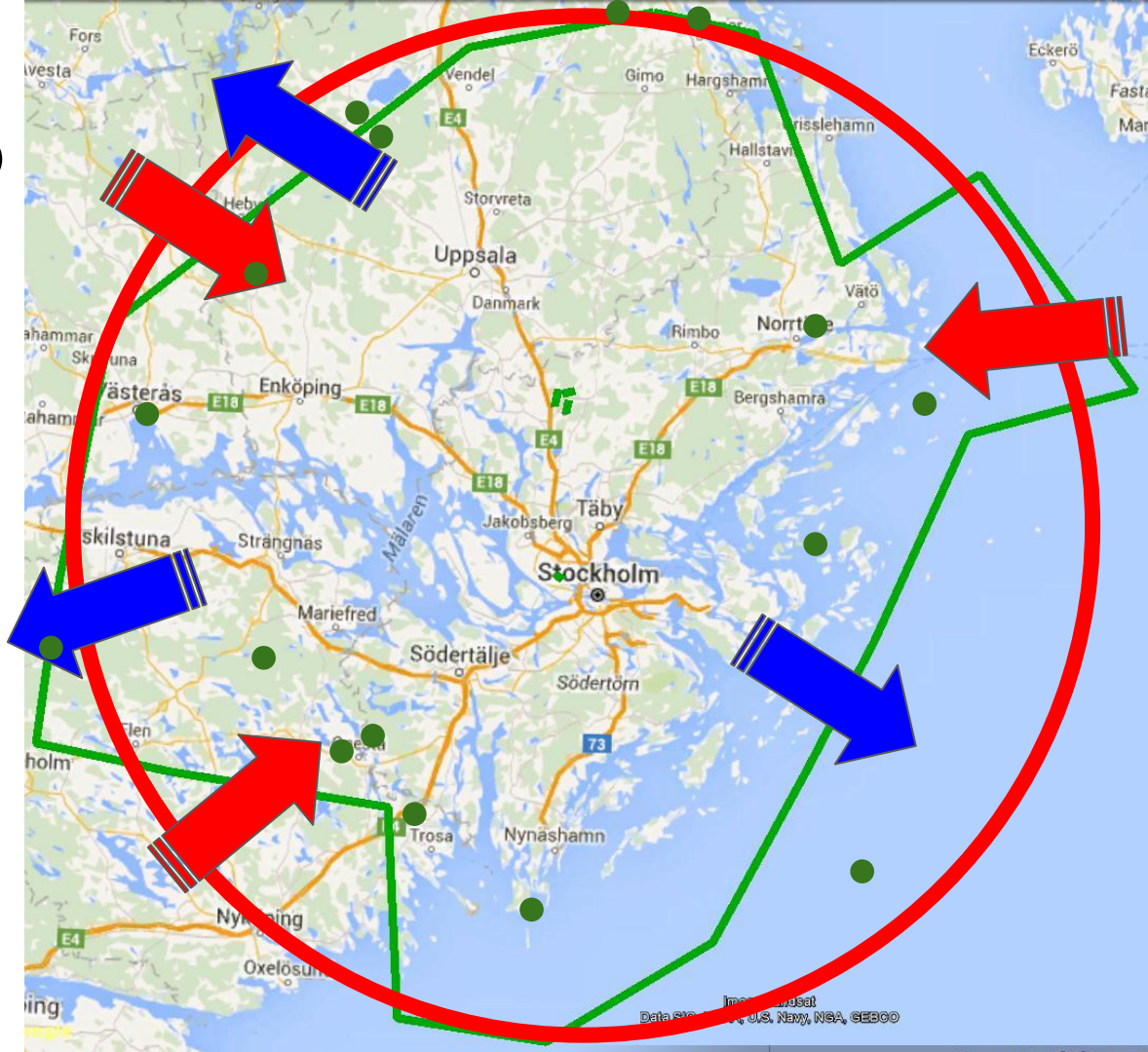
Problem shaping up

Output

entry/exit point
for each flight

Input

- resources
 - entry/exit points
- demand
 - ?



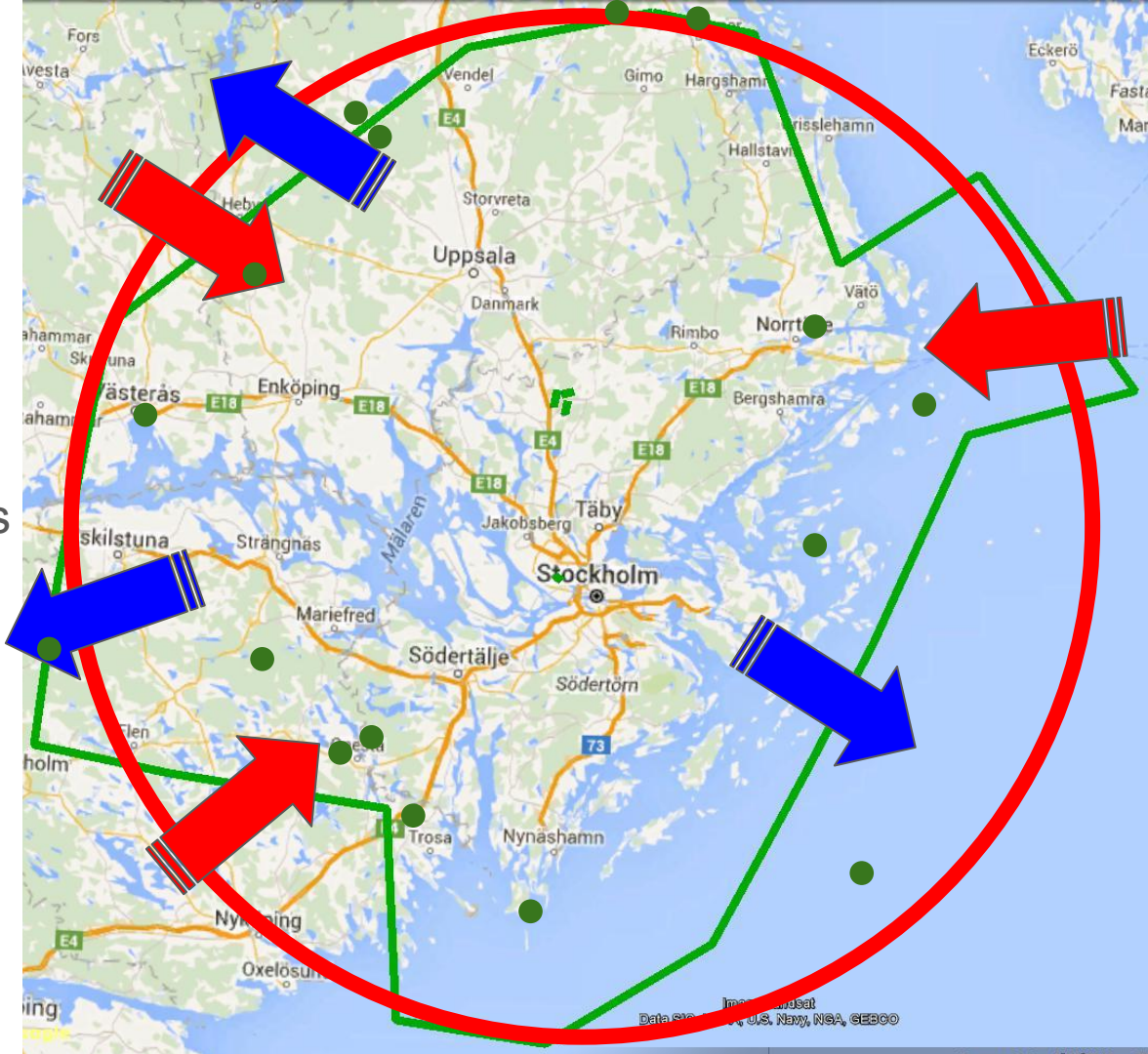
Demand

Mining historical data

- EUROCONTROL's DDR2
- .so6: SAAM 4D trajectories last filled flight plans
- to/from S-TMA in 2014

Other possible demand definitions

- Simulated demand
 - x2, x3, ...
- Projected demand
 - Random process, ...



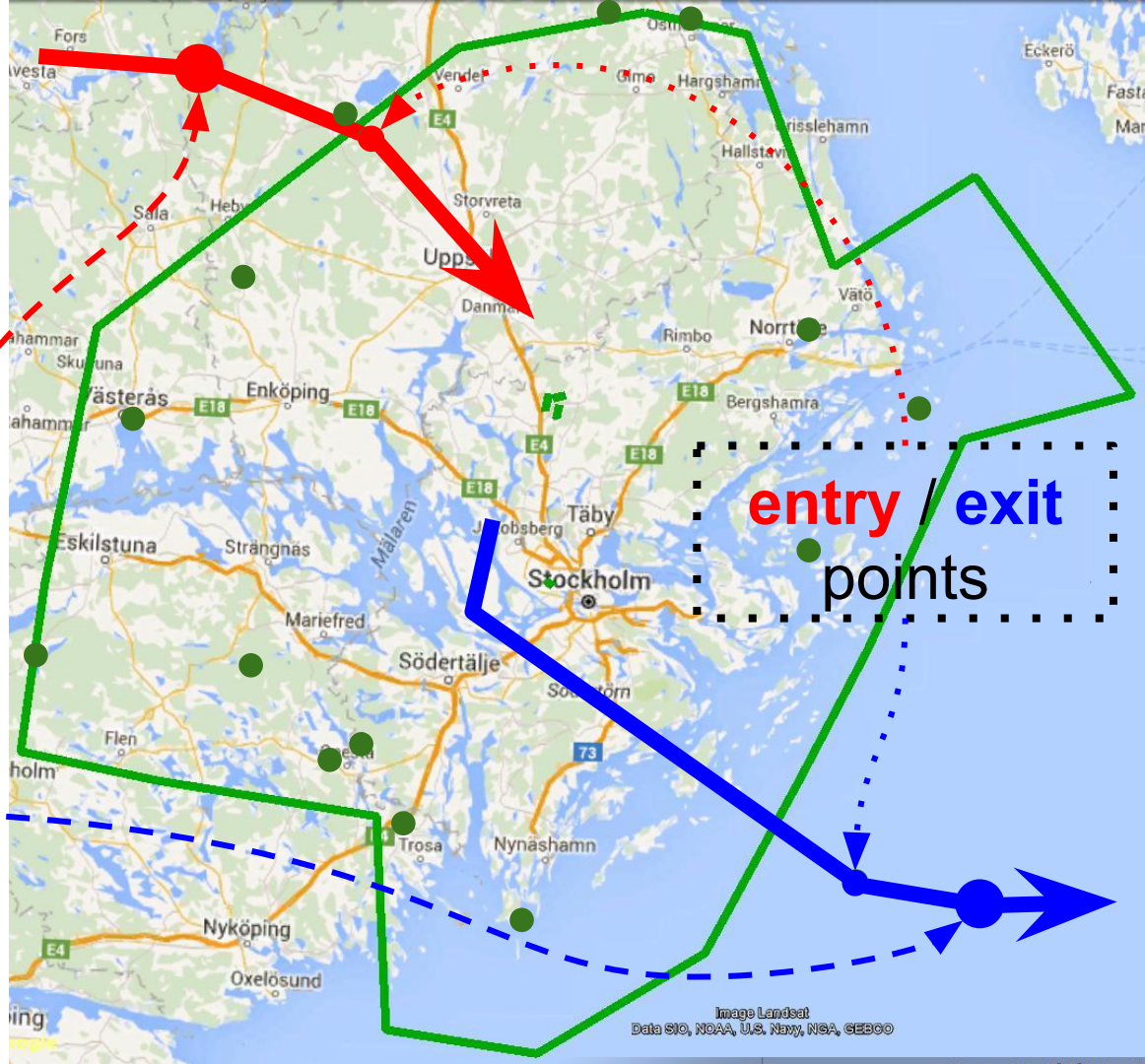
For each flight

Extract

- last point before TMA entrance for **in-flights**
- first point after TMA exit for **out-flights**

Call it **feeder**

Path before/after feeder --
outside TMA designer interest

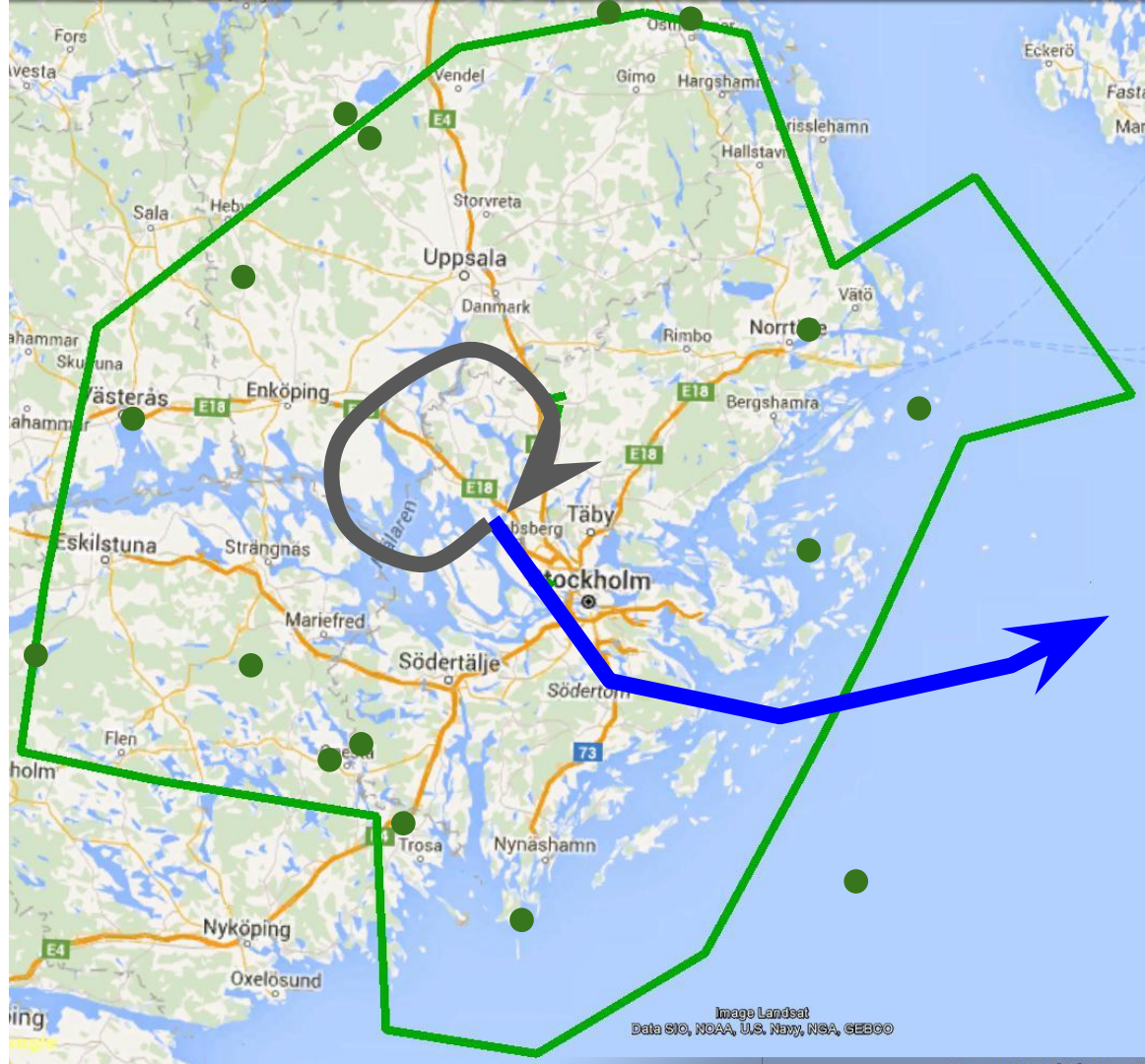


Minor cleanup

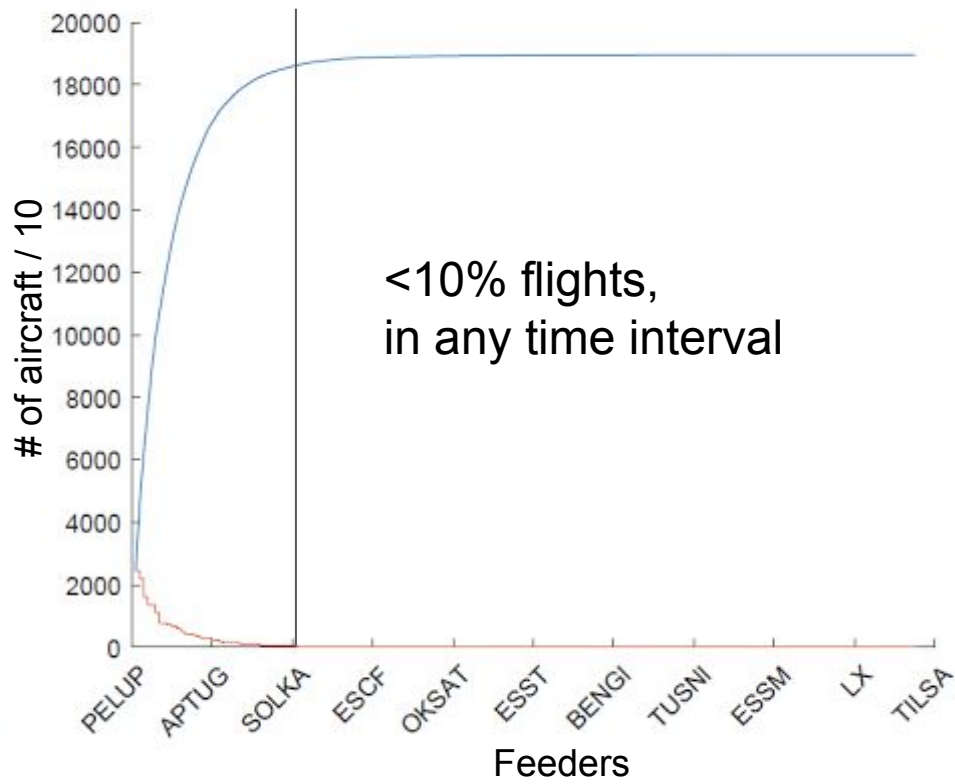
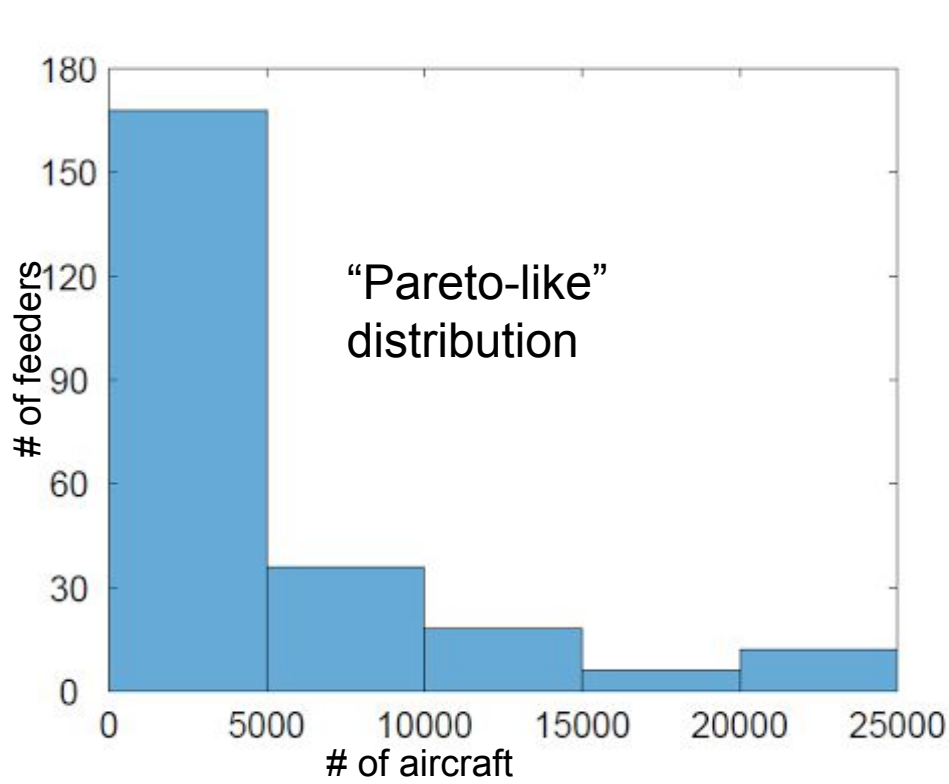
Excluded flights

- not through an echart point
- circular
- ESCM, ESOW, ESSU
 - small airfields in the TMA
- ...

~200 flights overall



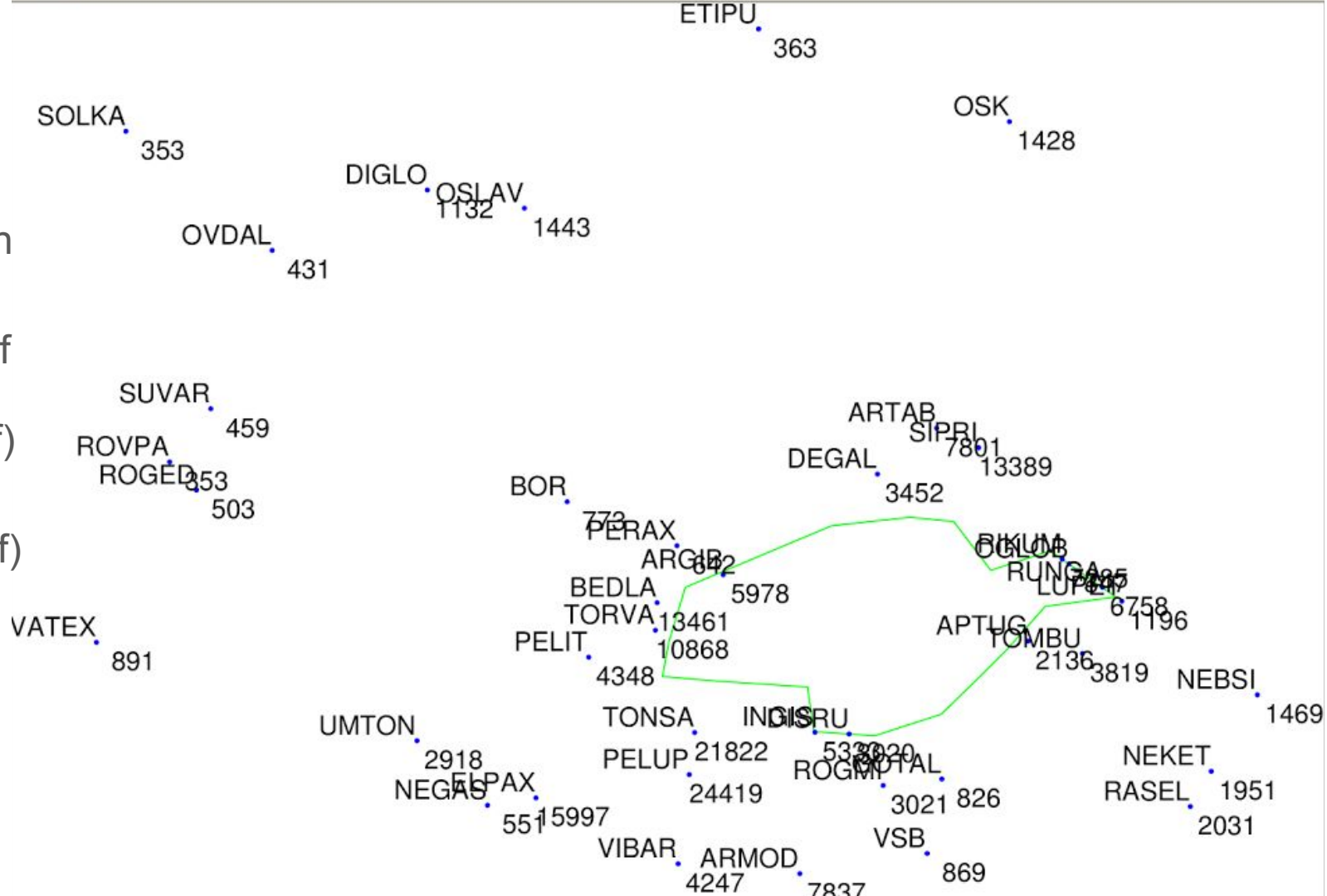
~~Major cleanup~~ Preprocessing: Feeder usage statistics



Demand

Flights through
40 feeders,
for each flight f

- feeder $F(f)$
- $RWY(f)$
- time at $F(f)$
- in/out
- a/c type
- ...



Demand

Flights through
40 feeders,
for each flight f

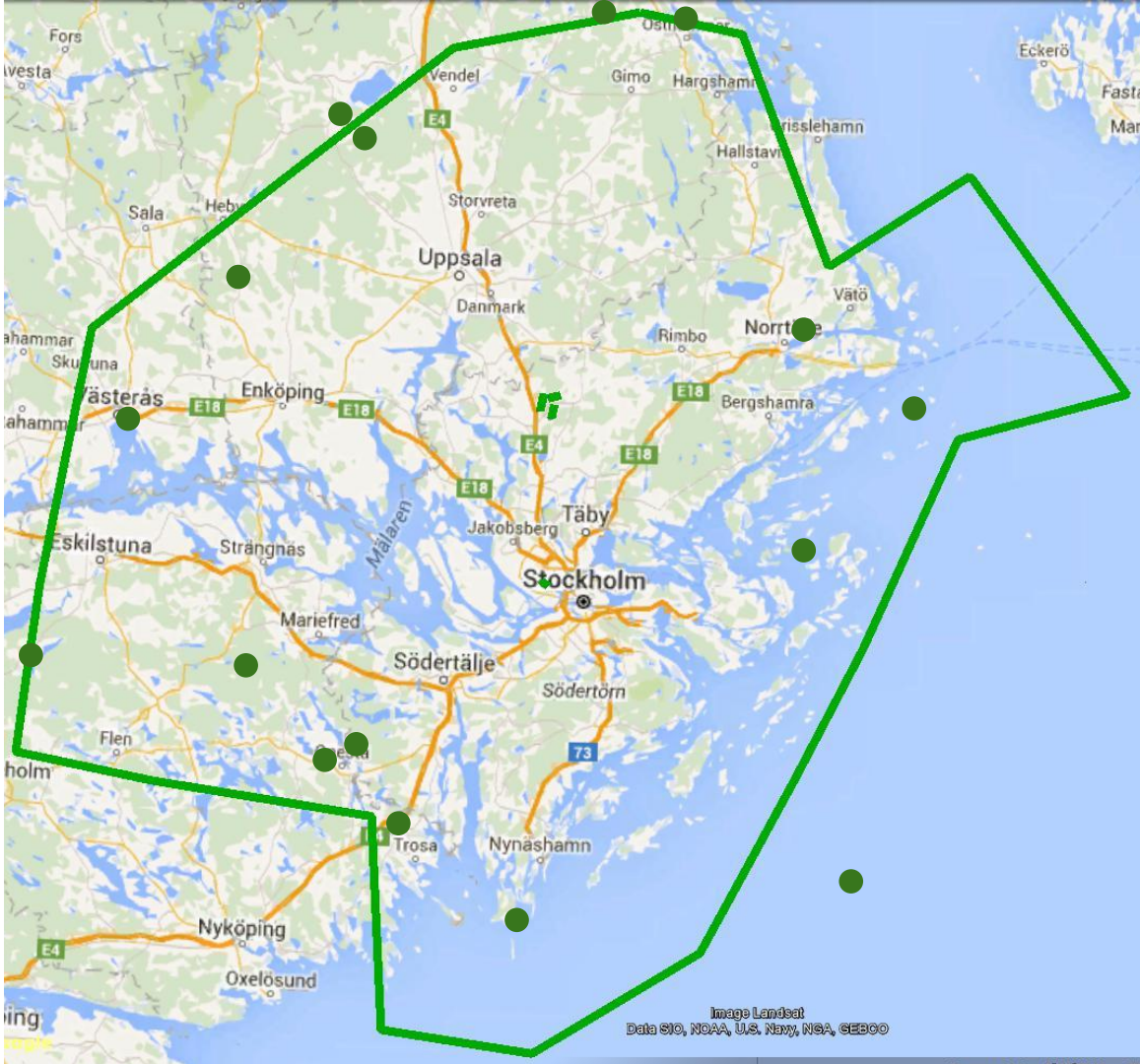
- feeder $F(f)$
- $RWY(f)$
- time at $F(f)$
- in/out
- a/c type
- ...



Assignment

Resource

Entry/exit
points



Before assignment...

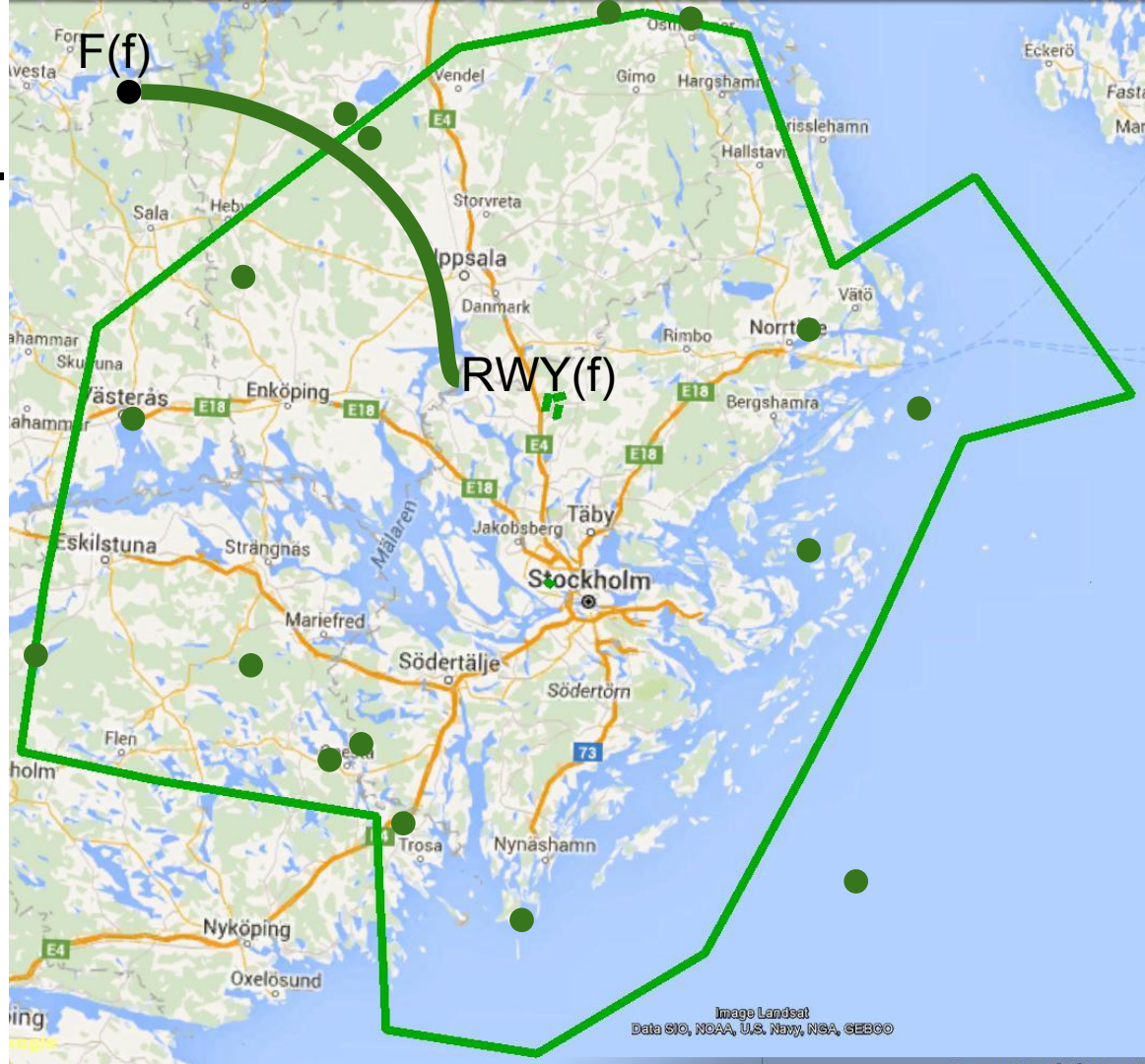
“Airline dream”:

Great Circle path

$$\text{GCD}(f) = \text{GCD}(F(f), \text{RWY}(f))$$

$$\text{GCDF} = \sum_f \text{GCD}(f)$$

Far from reality,
“ATCOs nightmare”,
ignores even entry/exit points,
...



GCD-Greedy

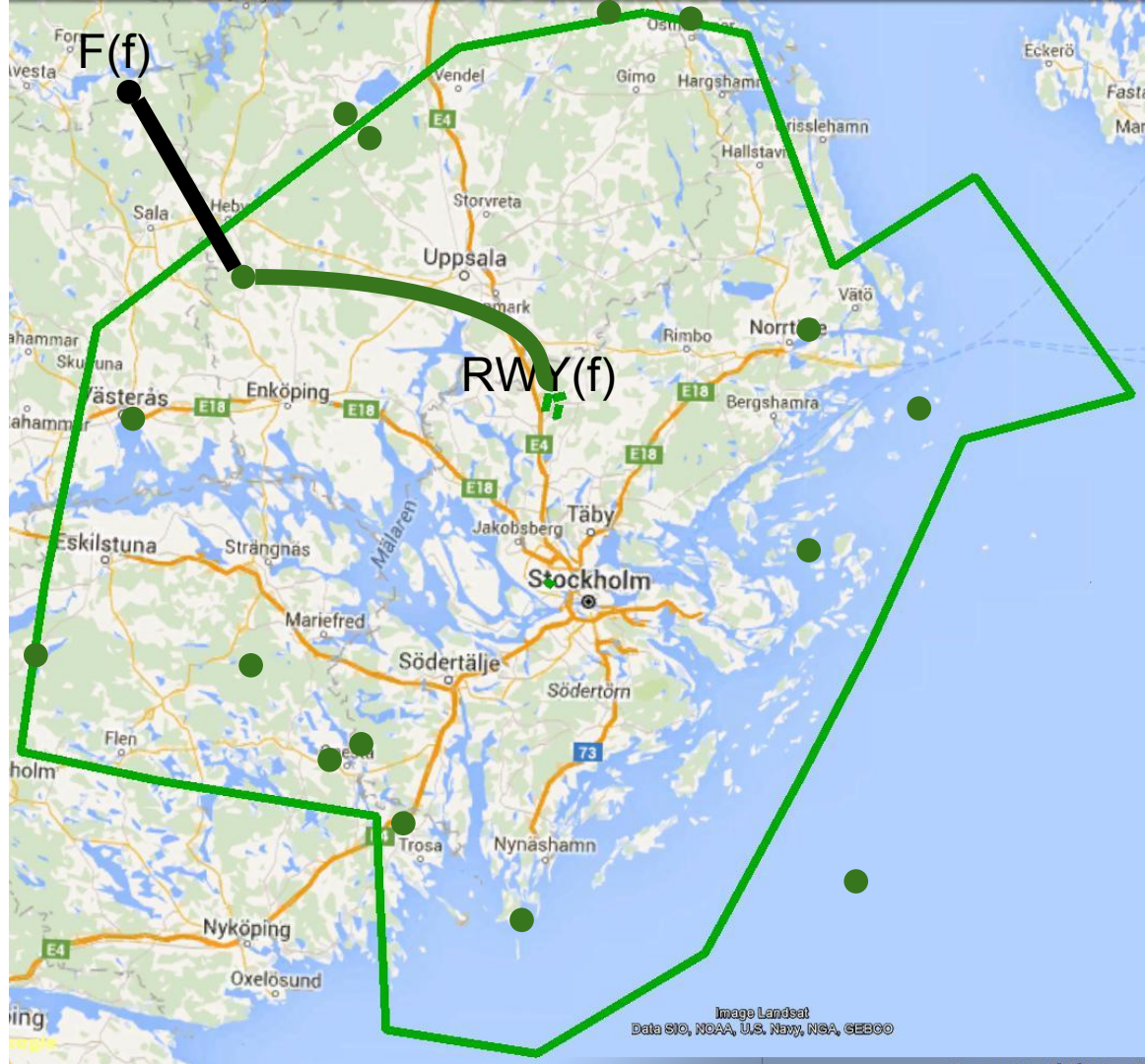
“Airline dream” s.t. use of entry/exit pts

$$w(F(f), E) = \text{GCD}(F(f), E) + \text{GCD}(E, \text{RWY}(f))$$

$$\text{GCD-Greedy}(f) = \min_E w(F(f), E)$$

$$\text{GCD-Greedy} = \sum_f \text{GCD-Greedy}(f)$$

Unstructured FF in TMA,
“ATCOs bad dream”, ...



Current-Greedy

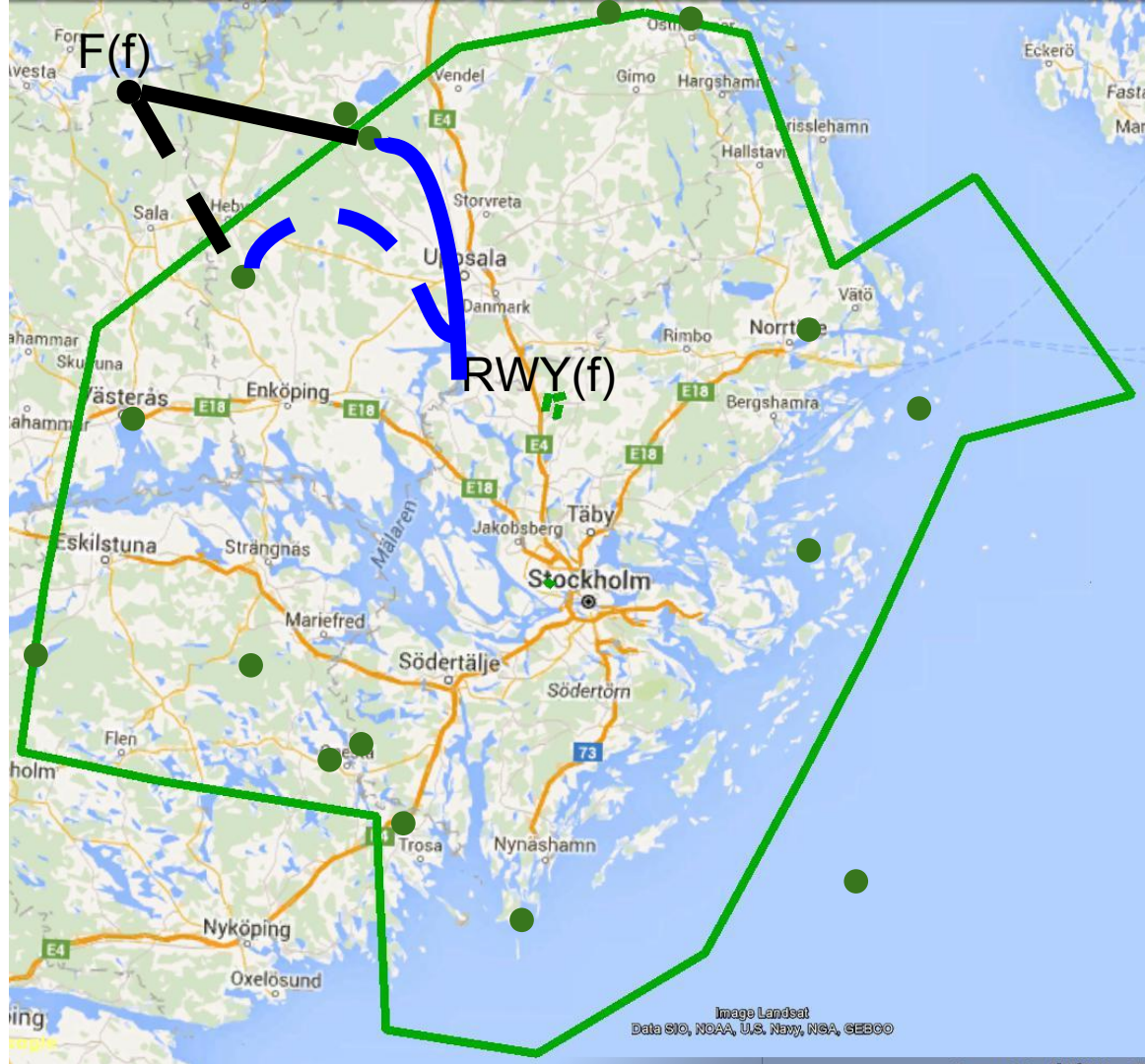
“Airline dream” s.t. use of entry/exit pts and STARs/SIDs

$$w(F(f), E) = \text{GCD}(F(f), E) + \text{Current}(E, \text{RWY}(f))$$

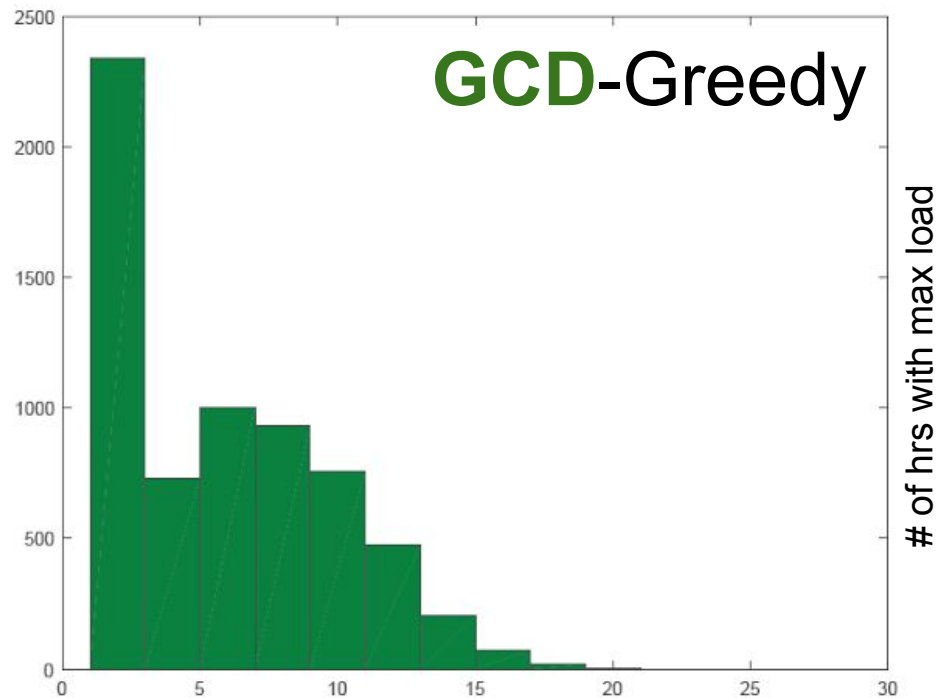
$$\text{Current-Greedy}(f) = \min_E w(F(f), E)$$

$$\text{Current-Greedy} = \sum_f \text{Current-Greedy}(f)$$

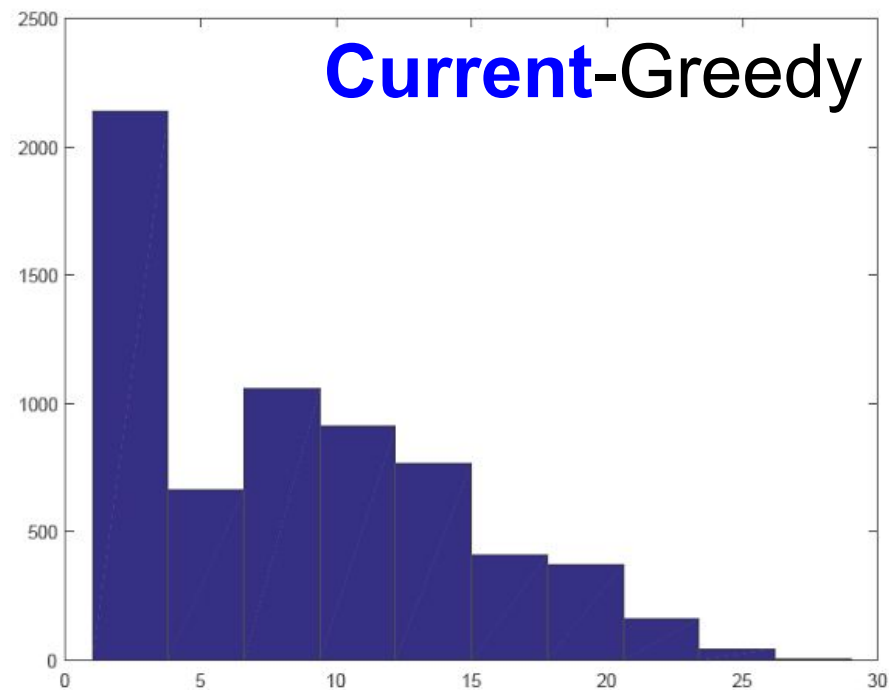
Structured flow in TMA, but potentially overloaded points...



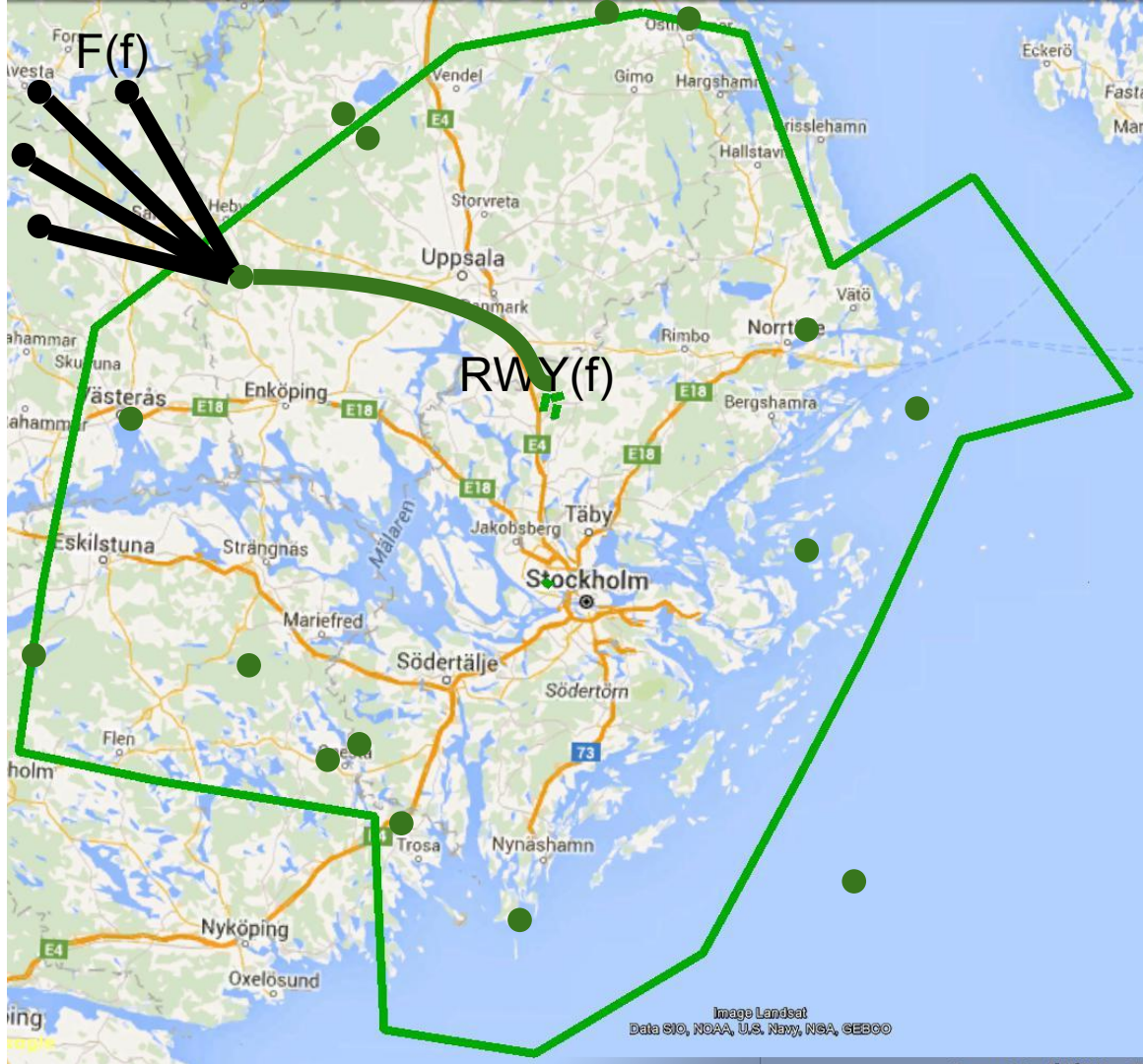
Points usage statistics



max point load (# of aircraft)



- Split time into intervals of length $T = 1$ hr
 - standard in ATM?
 - $T = 30\text{min}$, 1.5hr are OK too
 - rolling horizon (20/60min)
 - ...
- Within every interval any entry / exit point has $\leq N = 7$ flights
 - historical max load (2014)
 - just total, separation ignored
 - $\text{cost}(N)$ dependence below



Minimum-weight capacitated one-side-perfect matching in weighted complete bipartite graph

Graph on 2 sets (bipartite)

- edge between any F, E (complete)
- $w(F, E)$: edge weight (weighted)

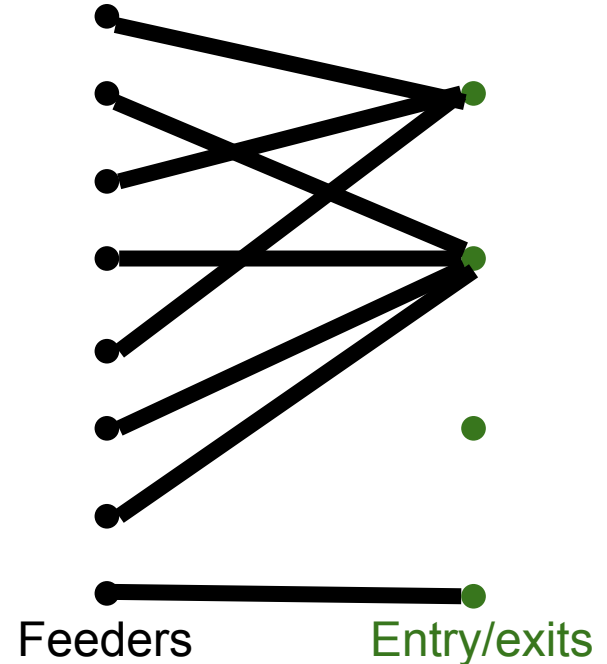
(N-)Matching: set of edges, s.t.

- any F incident to an edge of M (perfect)
- any E incident to $\leq N$ edges of M (capacitated)

Min-weight matching (w-min N-matching):

N-matching with min total edge weight

Efficient algorithms exist (reduce to mincost flow)



GCD-Match

$$w(F(f), E) = \text{GCD}(F(f), E) + \text{GCD}(E, \text{RWY}(f))$$

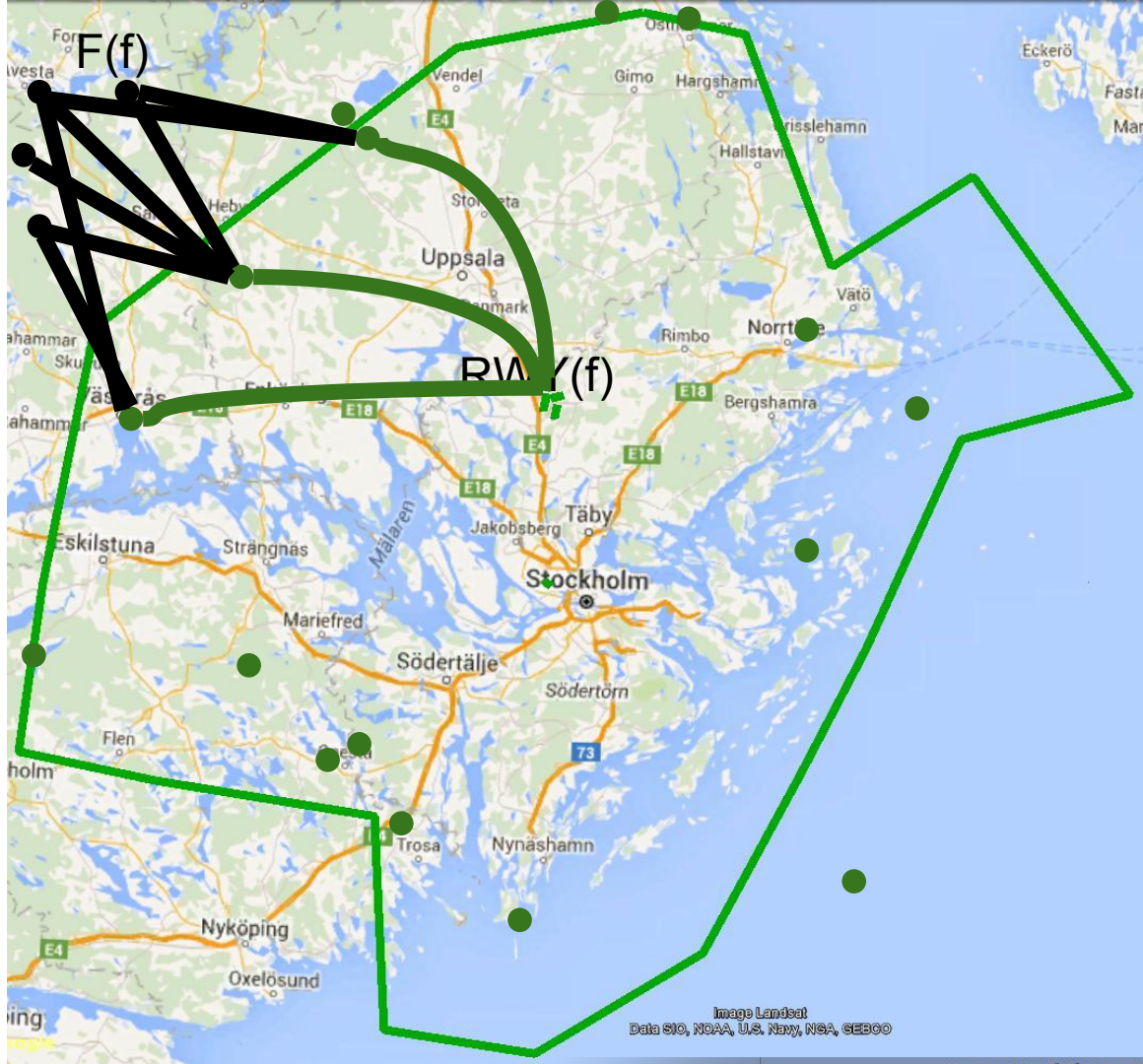
For each hour h

$$M_h^* = \text{w-min N-matching}$$

GCD-Match =

$$\sum_h M_h^*$$

No overloaded points, but
unstructured FF in TMA
("ATCOs bad dream"), ...



Current-Match

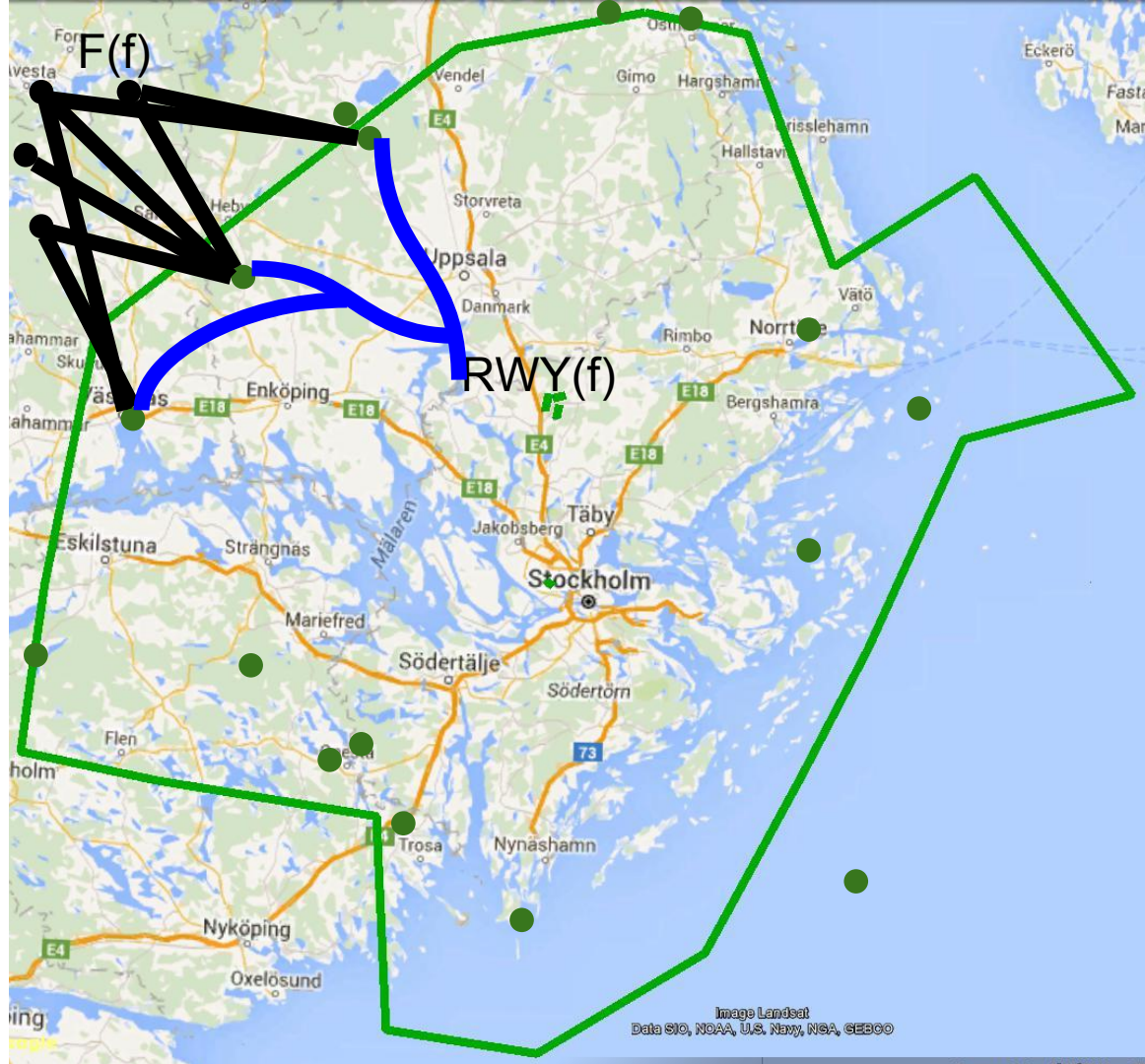
$$w(F(f), E) = \text{GCD}(F(f), E) + \text{Current}(E, \text{RWY}(f))$$

For each hour h

$$M_h^* = \text{w-min 7-matching}$$

Current-Match =

$$\sum_h M_h^*$$

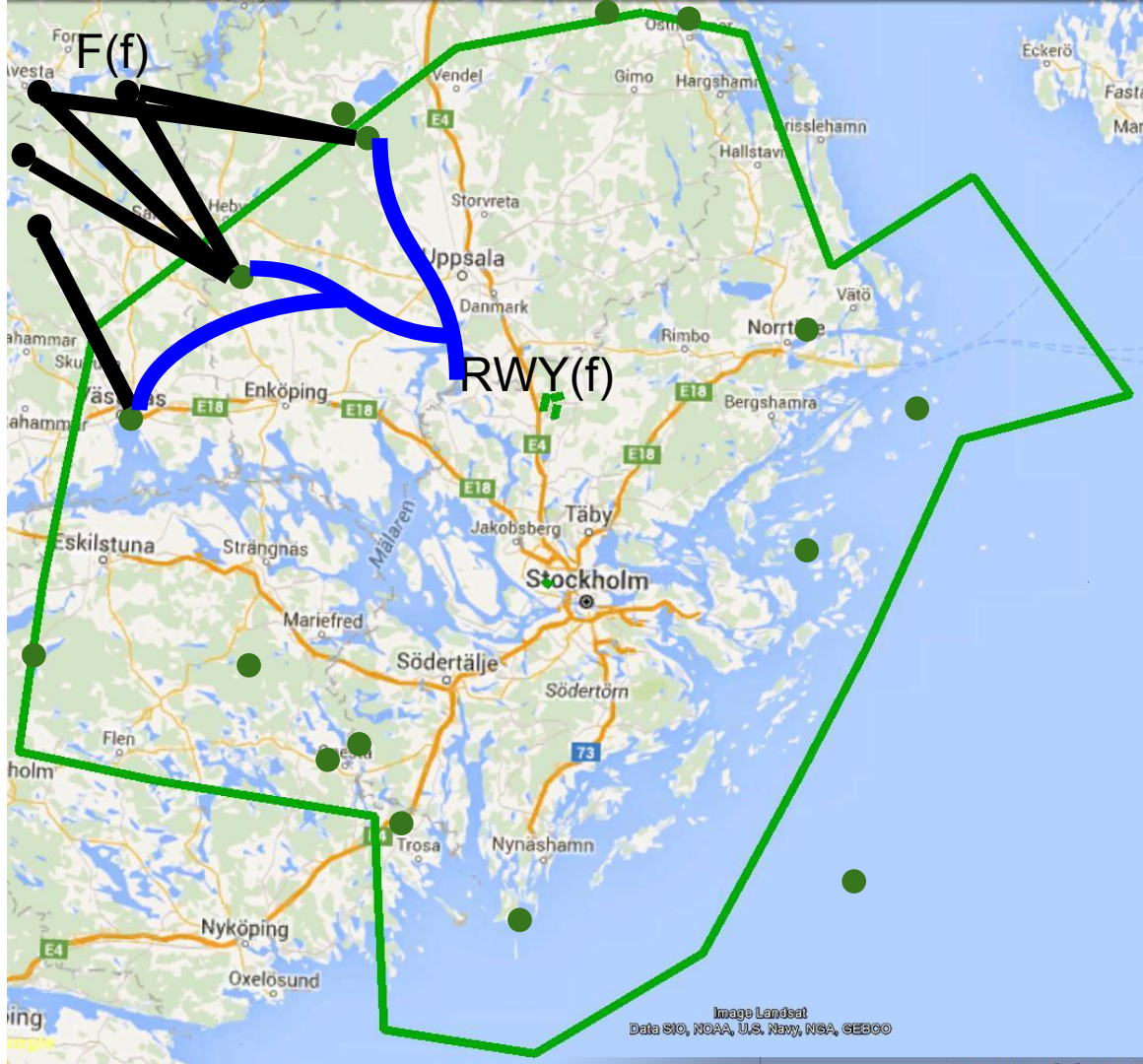


Current-Current

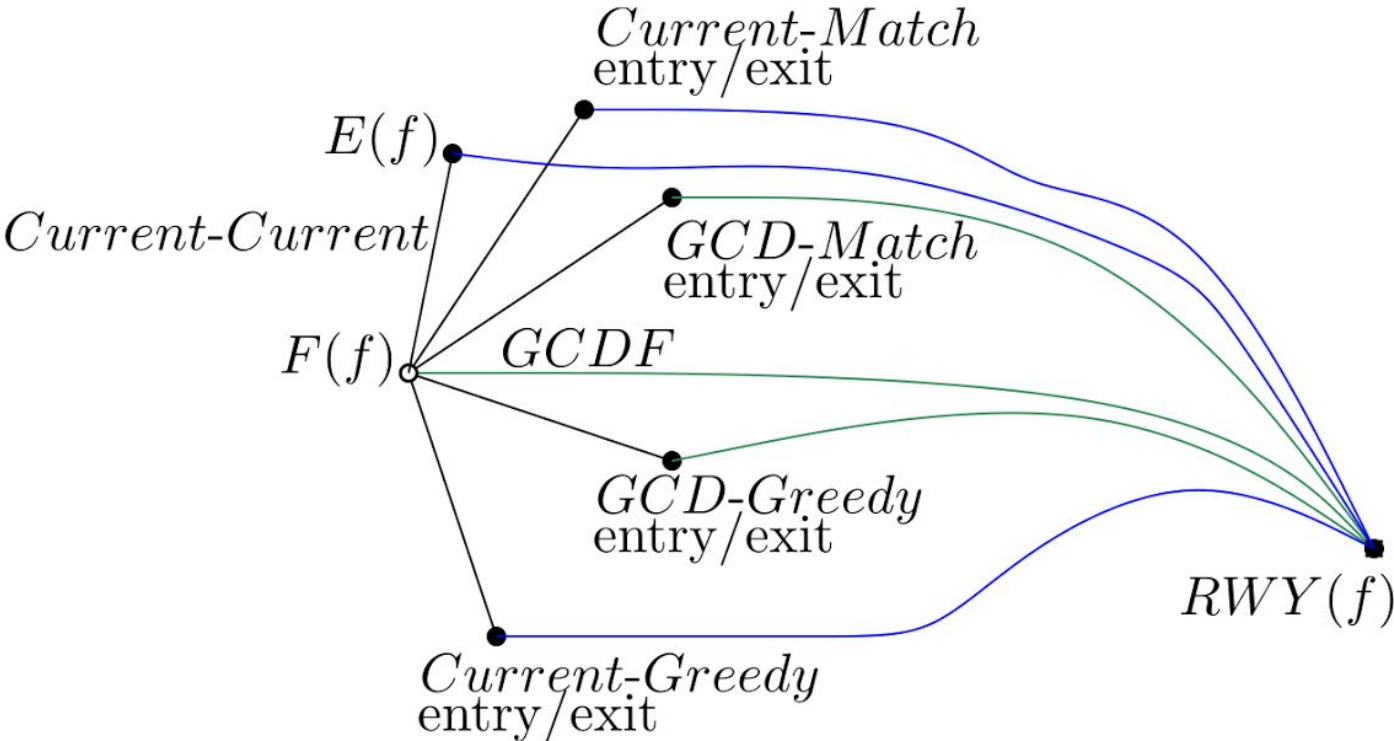
Actual (historical)
flow distance

$$\text{Current-Current}(f) = \text{GCD}(F(f), E(f)) + \text{GCD}(E(f), RW(f))$$

$$\text{Current-Current} = \sum_f \text{Current-Current}(f)$$



	GCD	STARs/SIDs
Greedy	<i>GCD-Greedy</i>	<i>Current-Greedy</i>
Coordinated	<i>GCD-Match</i>	<i>Current-Match</i>



	GCD	STARs/SIDs
Greedy	<i>GCD-Greedy</i>	<i>Current-Greedy</i>
Coordinated	<i>GCD-Match</i>	<i>Current-Match</i>

<i>GCDF</i>	15921330	85.6
<i>GCD-Greedy</i>	15992796	86.0
<i>Current-Greedy</i>	17564138	94.5
<i>GCD-Match</i>	16031315	86.2
<i>Current-Match</i>	17762601	95.5
<i>Current-Current</i>	18799869	101.1

GCD-Greedy – *Current-Greedy*: cost of STARs/SIDs

GCD-Match – *Current-Match*: similar (STARs/SIDs stretch factor)

<i>GCD</i>	15921330	85.6
<i>GCD-Greedy</i>	15992796	86.0
<i>Current-Greedy</i>	17564138	94.5
<i>GCD-Match</i>	16031315	86.2
<i>Current-Match</i>	17762601	95.5
<i>Current-Current</i>	18799869	101.1

GCD-Match – *GCD-Greedy*: human factors

Current-Match – *Current-Greedy*: similar (sector load ignored)

<i>GCDF</i>	15921330	85.6
<i>GCD-Greedy</i>	15992796	86.0
<i>Current-Greedy</i>	17564138	94.5
<i>GCD-Match</i>	16031315	86.2
<i>Current-Match</i>	17762601	95.5
<i>Current-Current</i>	18799869	101.1

GCD-Greedy – *GCDF*: cost of flying in/out via the pts

small (pts spread evenly around); Feeders--Points graph is a good *spanner*

<i>GCDF</i>	15921330	85.6
<i>GCD-Greedy</i>	15992796	86.0
<i>Current-Greedy</i>	17564138	94.5
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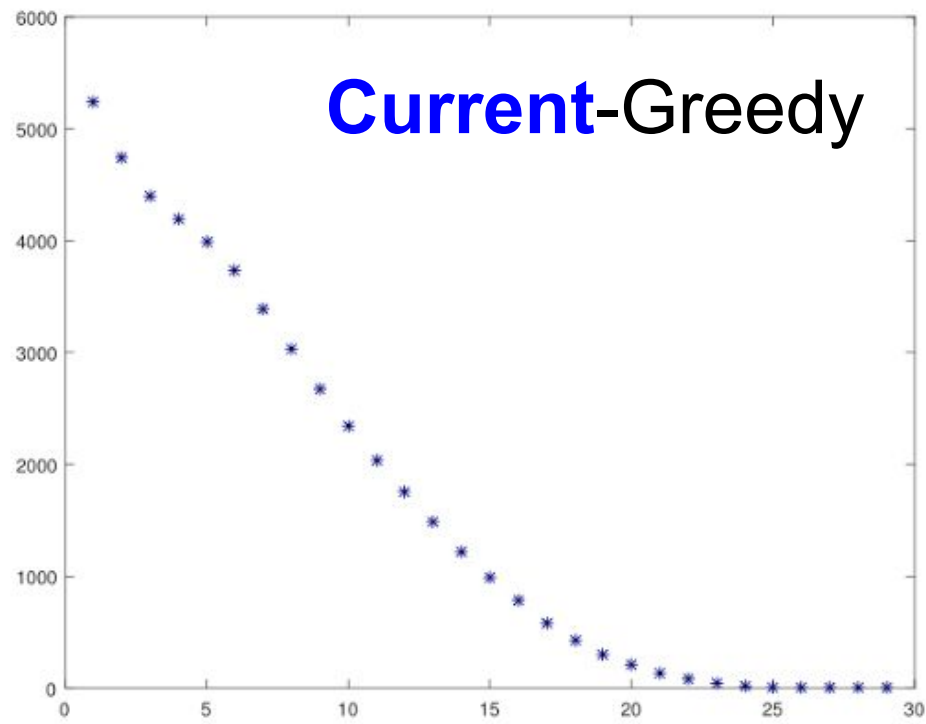
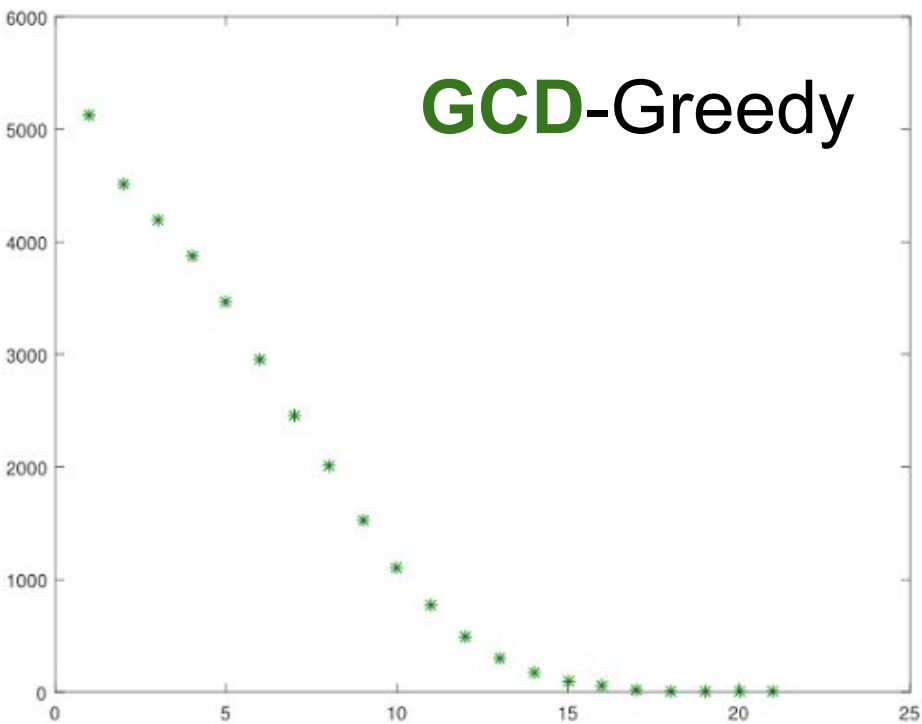
CurrentCurrent – *GCDF*: overall cost of control

~ price of anarchy: best centralized outcome / best individualized outcome

<i>GCDF</i>	15921330	85.6
<i>GCD-Greedy</i>	15992796	86.0
<i>Current-Greedy</i>	17564138	94.5
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<i>Current-Match</i>	17762601	95.5
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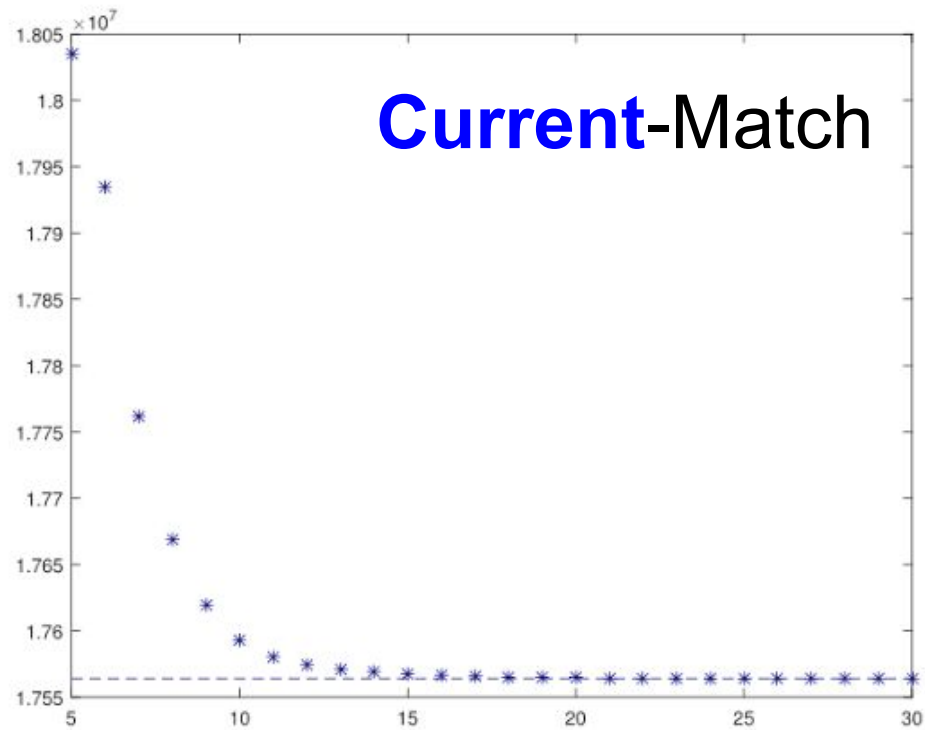
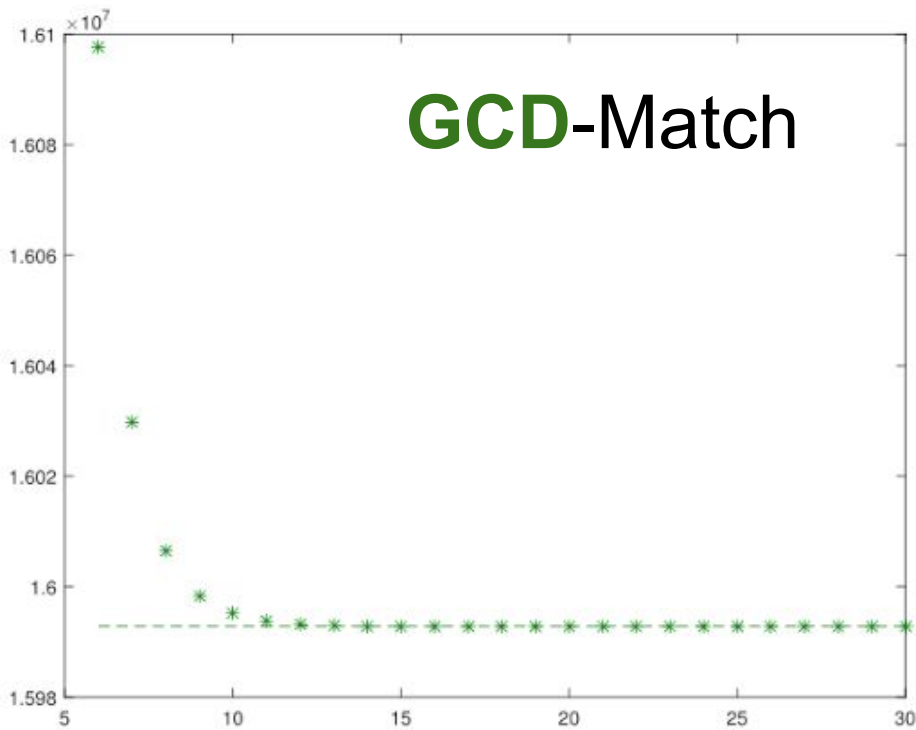
Greedy: overloaded_hrs(N)

N = 7 : ~1/2 of hrs are overloaded



Matching: cost(N)

High sensitivity to N around N=10-15



Summary

- Subproblem in TMA optimization
 - feeders--entry/exit points matching
- Local flow modification
 - keep the rest intact
- How much is the control?
 - where efficiency may be lost/gained
 - room for improvement
- Applicable to any TMA
 - human decides T and N
 - the rest is (almost) automated

Extensions

- Weigh distance w.r.t. a/c type
 - not all a/c are equal
 - noise, not only distance
- Bound sector load
 - not single point load
- Optimize entry/exit points locations
 - don't keep them fixed
- Re-sectorize
 - better locate the pts and
 - sector boundaries balance workload

!Happy



Matchings!

Tobias Andersson Granberg
Valentin Polishchuk

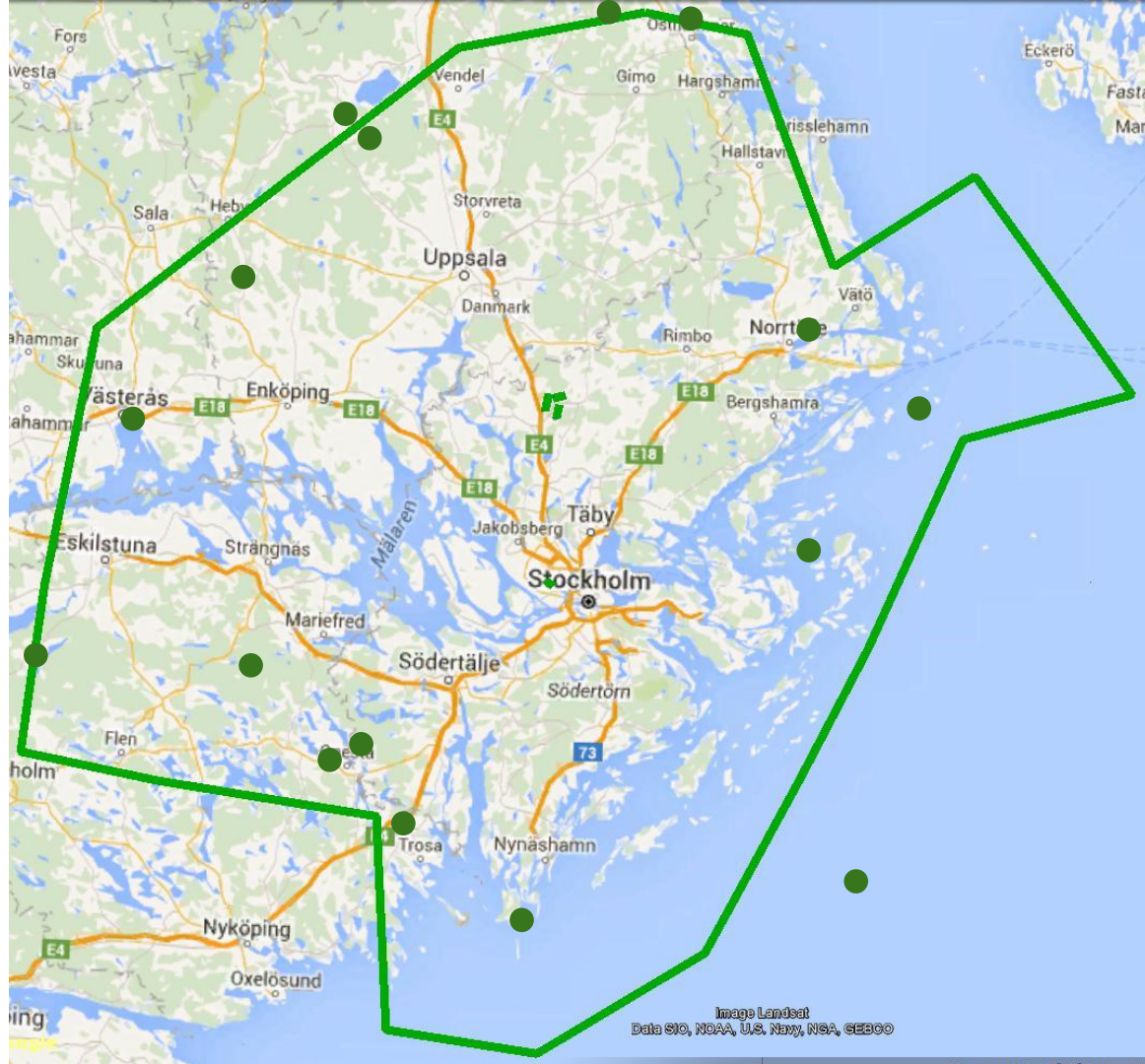
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Billy Josefsson



Linköping University





S-TMA
(with a
BMA
STAR
and
SID)

