Automated Separation for CDO-enabled Arrivals within TMA

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KTH VETENSKAP OCH KONST

CSA Centre for Sustainable Aviation

LFV

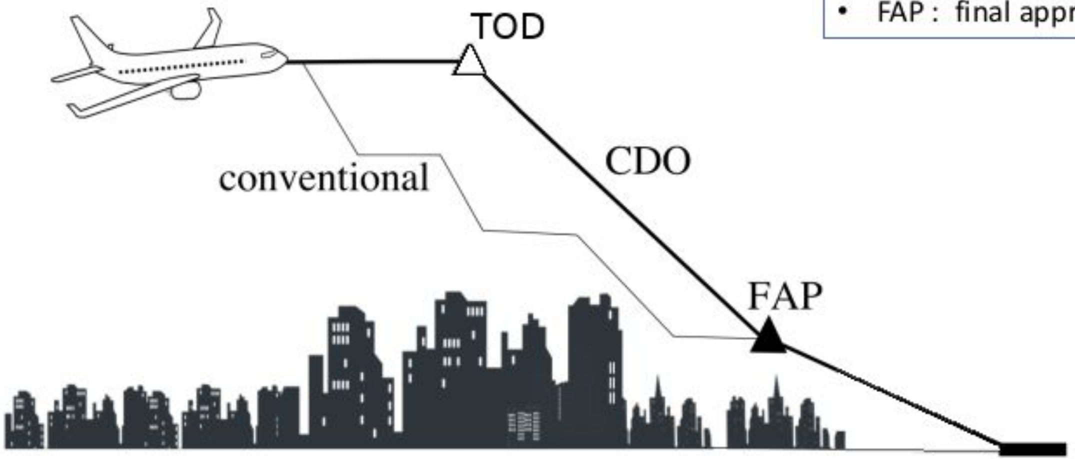
ODESTA project

Optimizing Aircraft Descent for Environmentally Sustainable Aviation

- Environmentally-friendly solutions
- Energy-neutral descent
- Fuel-optimal
- Reduced noise

CDOs: recap

- Continuous Descent Operations CDOs have shown important environmental benefits w.r.t. conventional (step-down) approaches



- TOD : top of descent
- FAP : final approach point

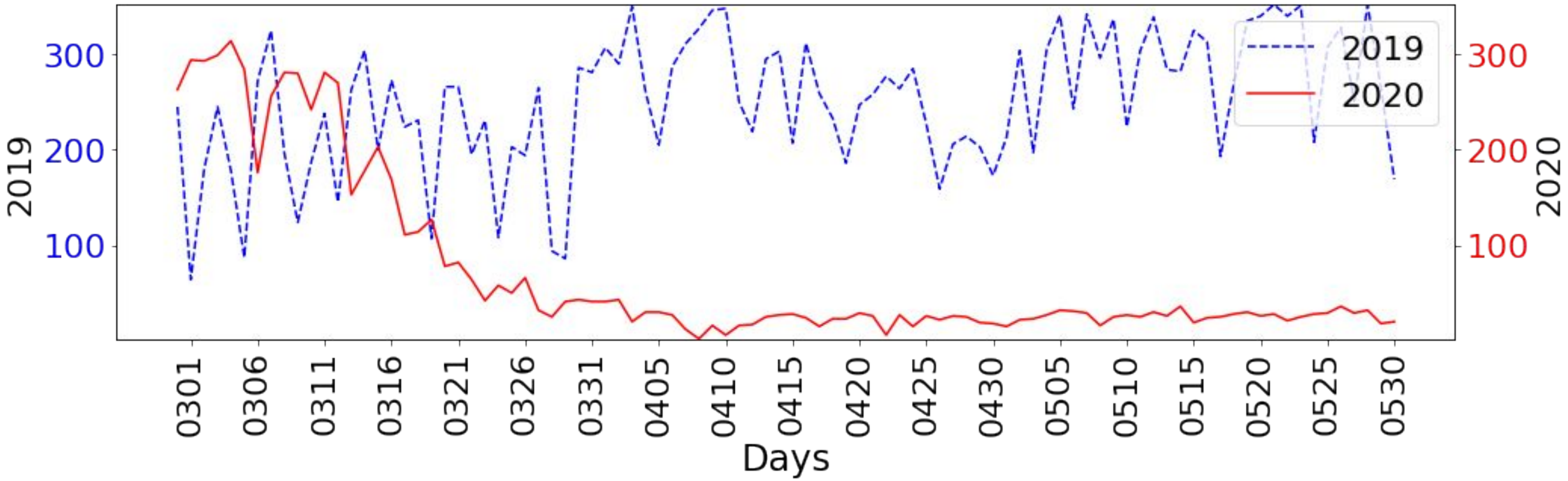
Goals

- Implement CDOs (Continuous Descent Operations) for all arrivals currently not widely used because of low predictability, hard to control

- Automated separation of arrivals within TMA to reduce complexity and ATCO's workload

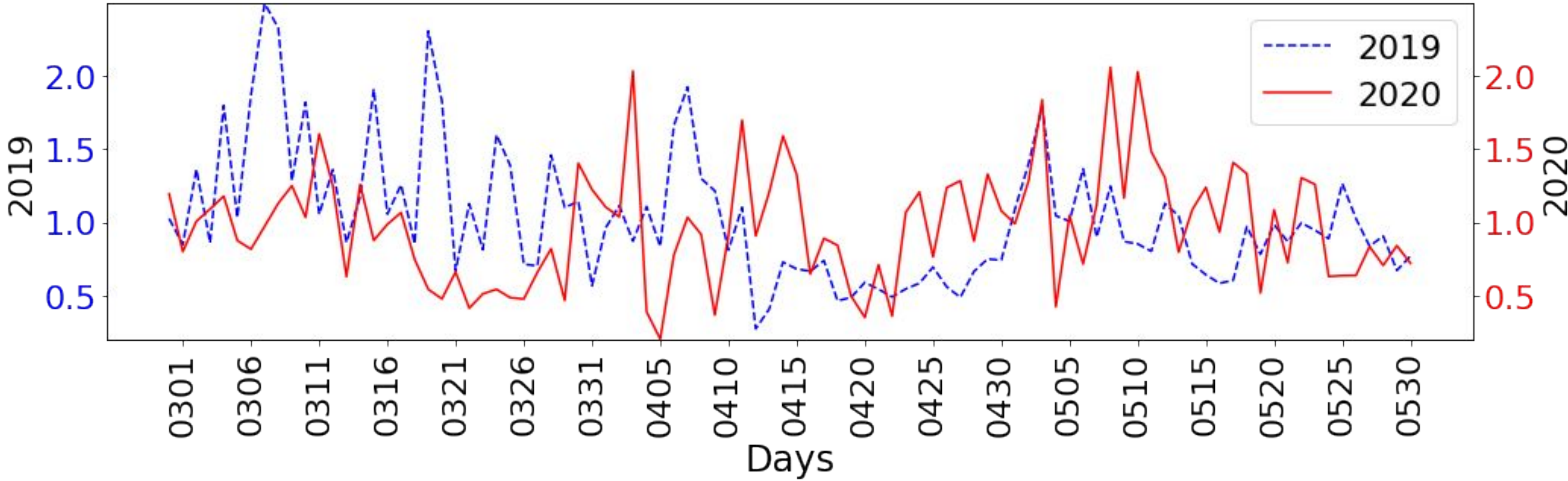
Motivation

COVID-19 impact: # flights spring 2019 vs spring 2020 (~89% reduction)



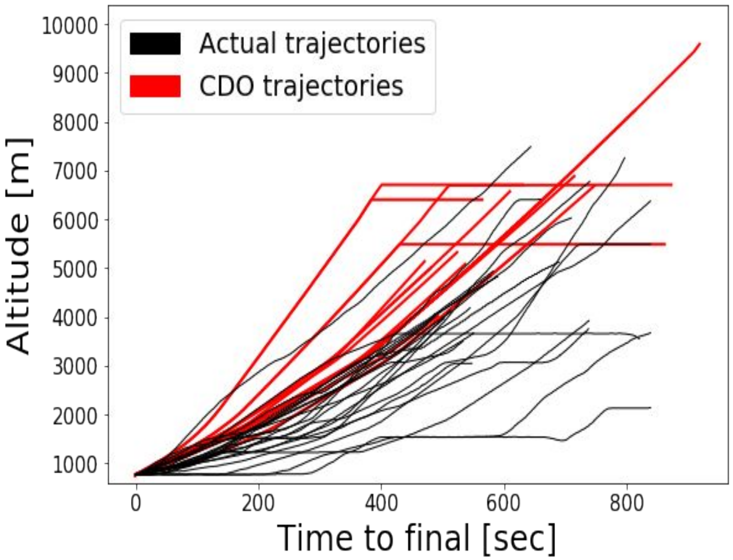
Motivation

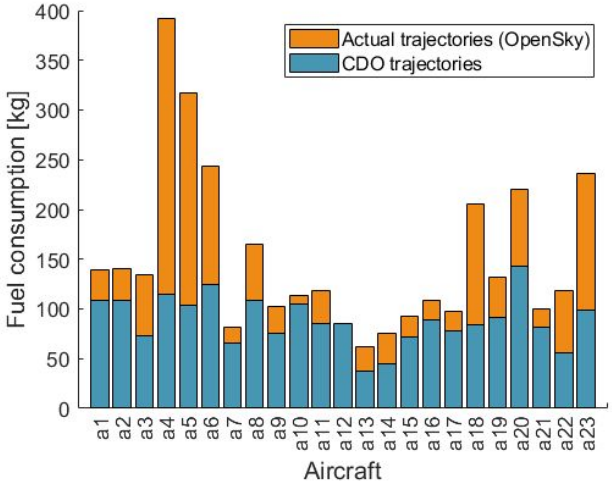
Vertical inefficiencies within TMA



Motivation

Vertical inefficiencies within TMA and associated extra fuel burn

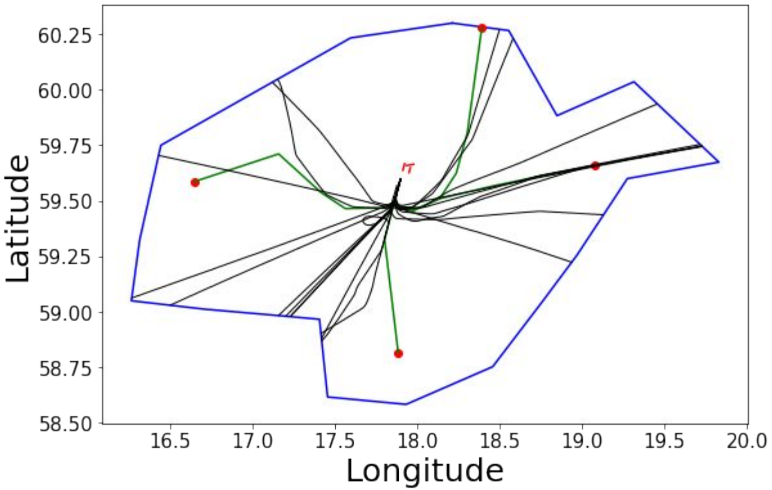


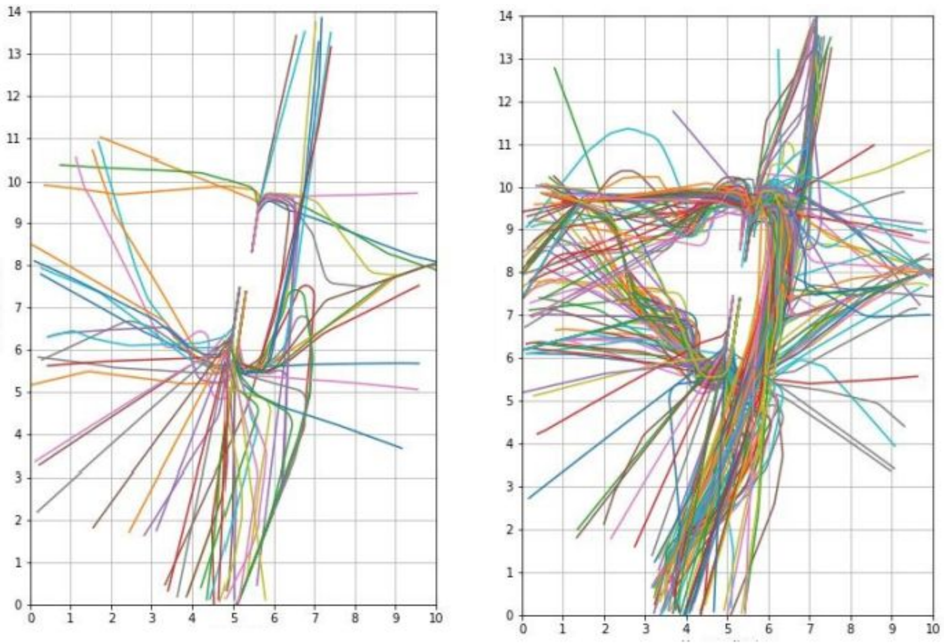


23 arrivals to Arlanda airport on May 4, 2020:
~1444 kgs (**42**% extra fuel burned)

Motivation

Horizontal inefficiencies





2020

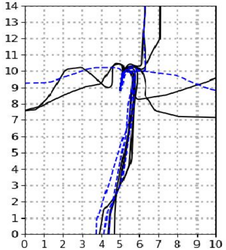
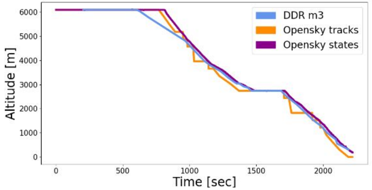
2018

ODESTA, IFWHEN, TMAKPI

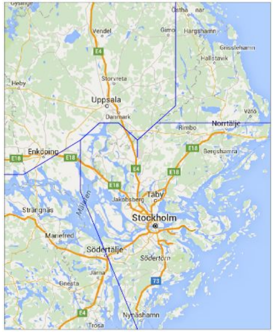
Optimizing Aircraft Descent for Environmentally SusTainable Aviation

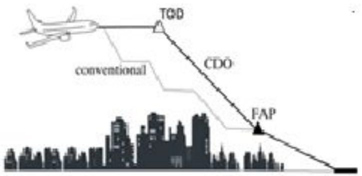
- ✔ Punctuality
- ✔ Fuel efficiency
- ✔ Vertical efficiency
- ✔ Noise footprint
- ✔ Weather impact
- ✔ Trade-offs

Impact of Fleet Diversity and WeatHer on Emissions, Noise and Predictability

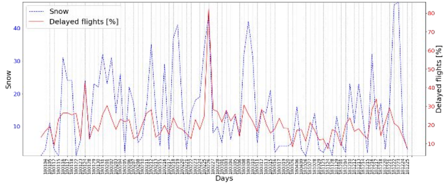



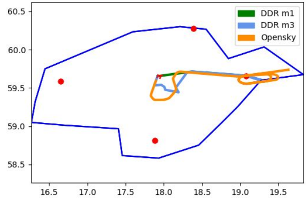
Towards Multidimensional Adaptive KPIs for operations assessment and optimization





Continuous Descent Operations:
Optimized wrt. fuel and noise





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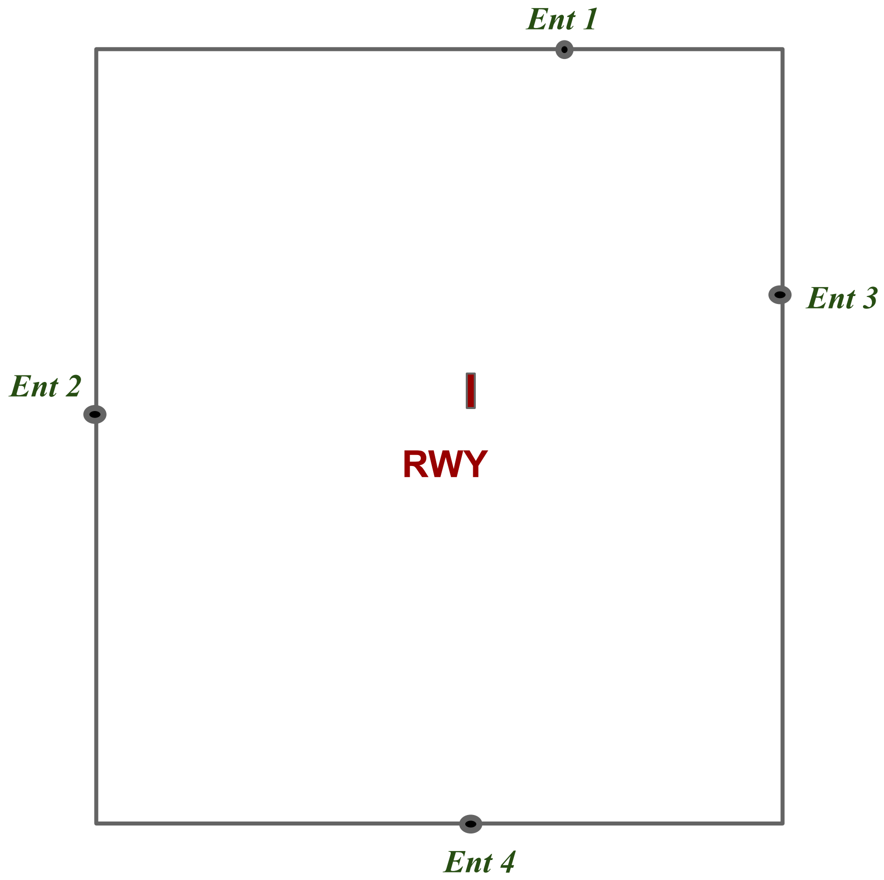
2-Phase Optimization

- ***Individual*** aircraft trajectory optimization (realistic CDOs speed profiles)

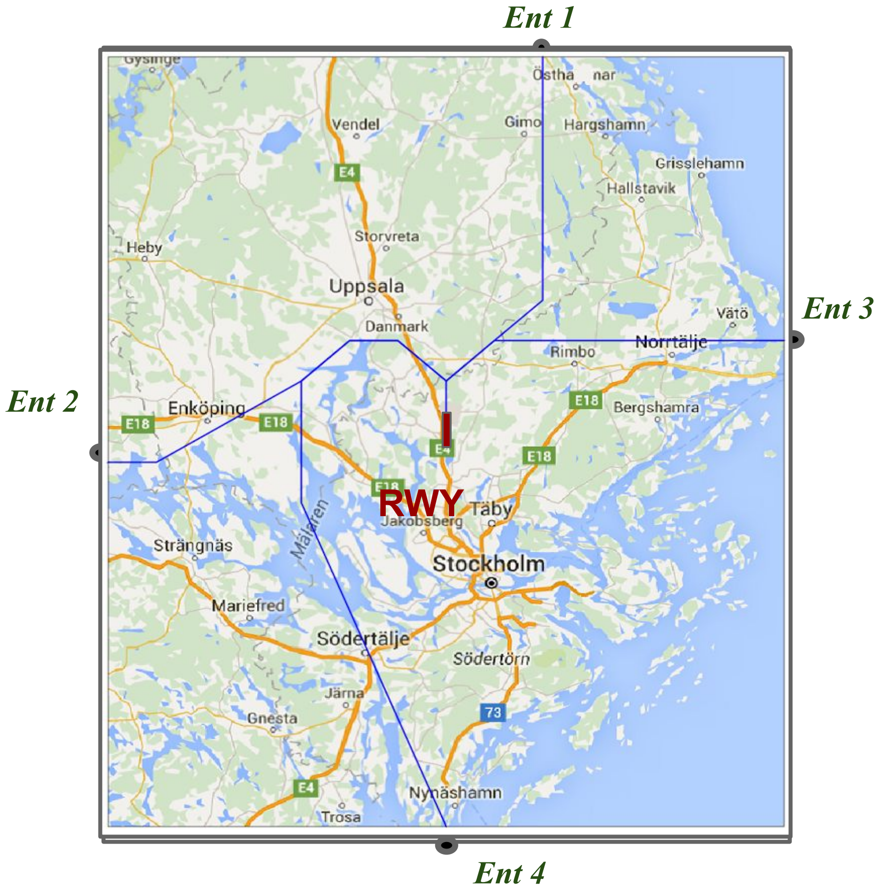
- Automated separation of ***multiple*** arrivals within TMA



Input

- Location and direction of the airport runway
- Locations of the entry points to the TMA
- Aircraft arrival times at the entry points for a fixed time period

  (*v1*: fixed, *v2*: flexible)
- Cruise conditions (altitude, true airspeed, distance to entry point) and aircraft type for CDO profile generation



Output

Optimal arrival tree

that merges traffic

from the entries to the runway

ensuring safe aircraft separation

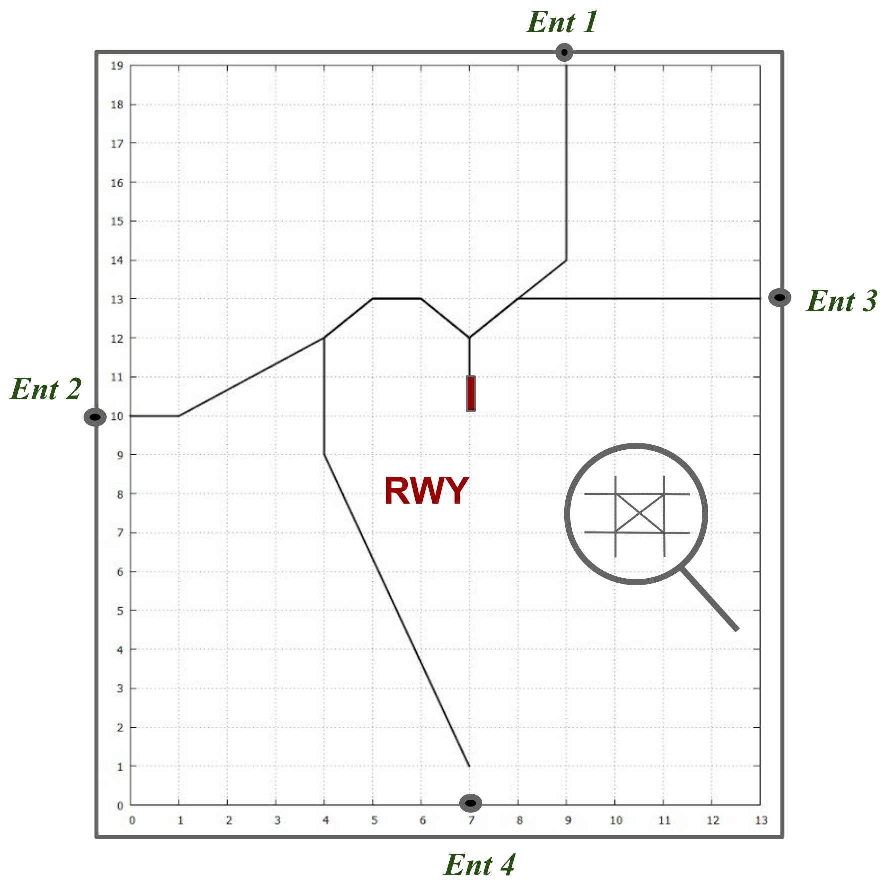
for the given time period

=

a set of time-separated **CDO-enabled** aircraft trajectories

optimized w.r.t. the traffic demand

during the given period



Grid-Based MIP Formulation

- Square grid in the TMA
- Every node connected to its 8 neighbours
- Snap locations of the entry points and the runway into the grid
- Grid cell side of the length *s* (*separation parameter*)
- Problem formulated as MIP

Based on flow MIP formulation for Steiner trees

Operational Requirements

- No more than two routes merge at a point
- Merge point separation
- No sharp turns
- Temporal separation of all aircraft along the routes
- All aircraft fly energy-neutral CDO:
  idle thrust, no speed brakes (noise avoidance)
- Smooth transition between consecutive trees when switching

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Realistic CDO Speed Profiles

- The trajectory is divided in two phases: the cruise phase prior the top of descent (TOD) and the idle descent

- The original cruise speed is not modified after the optimization process, so the two-phases optimal control problem can be converted into a **single-phase optimal control problem**

- BADA V4 is used to model the aircraft performance

Realistic CDO Speed Profiles

- The state vector represents the fixed initial conditions of the aircraft: TAS $\boldsymbol{v}$, altitude $\boldsymbol{h}$ and distance to go $\boldsymbol{s}$

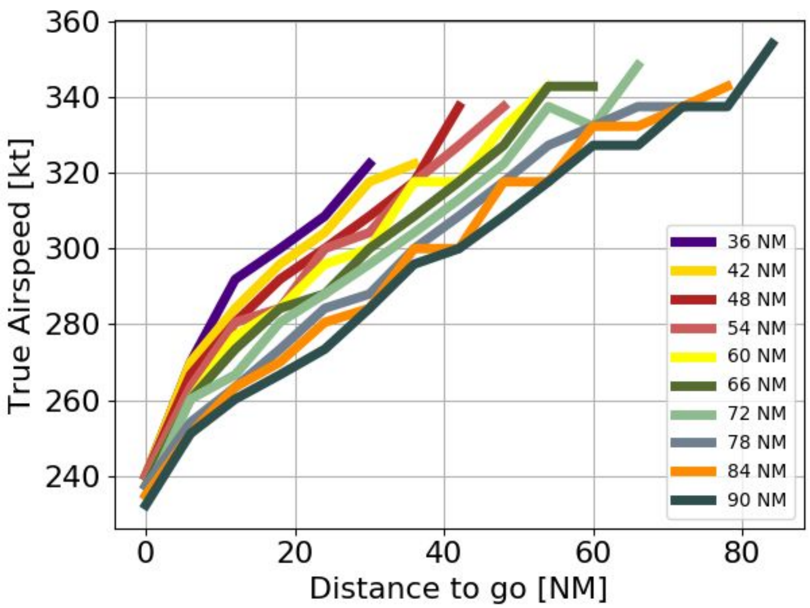
- To achieve environmentally friendly trajectories, **idle thrust** is assumed and **speed-brakes** use is **not allowed** throughout the descent → **energy-neutral** CDO

- The flight path angle is the only control variable in this problem → control vector $\boldsymbol{u}$

$$x = [v, h, s]$$
$$u = [\gamma]$$

Sáez, X. Prats , T. Polishchuk , V. Polishchuk , C.Schmidt. Automation for Separation with CDOs: Dynamic Aircraft Arrival Routes. AIAA Journal, published Online: 28 May 2020

CDO speed profiles inside TMA



Example of A320 speed profiles for different path lengths inside TMA

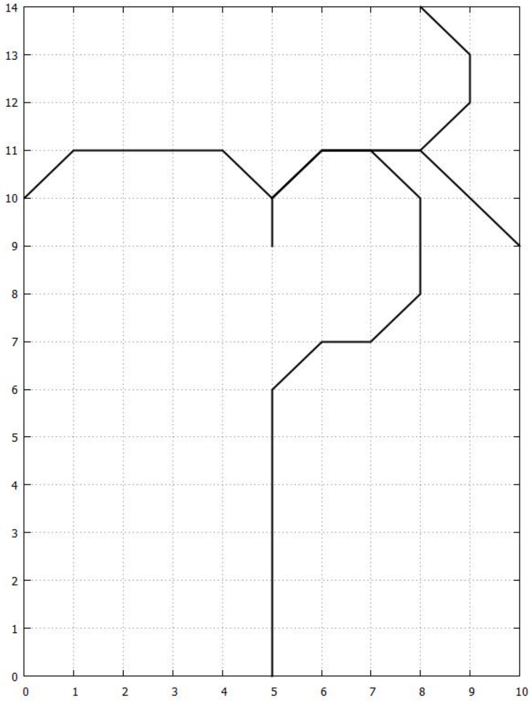
- ✓ A set of realistic alternative speed profiles for all *feasible route lengths* inside TMA
- ✓ Generated for all a/c types arriving to Arlanda during the given period
- ✓ Used as input to MIP

Experimental Study: Stockholm Arlanda Airport

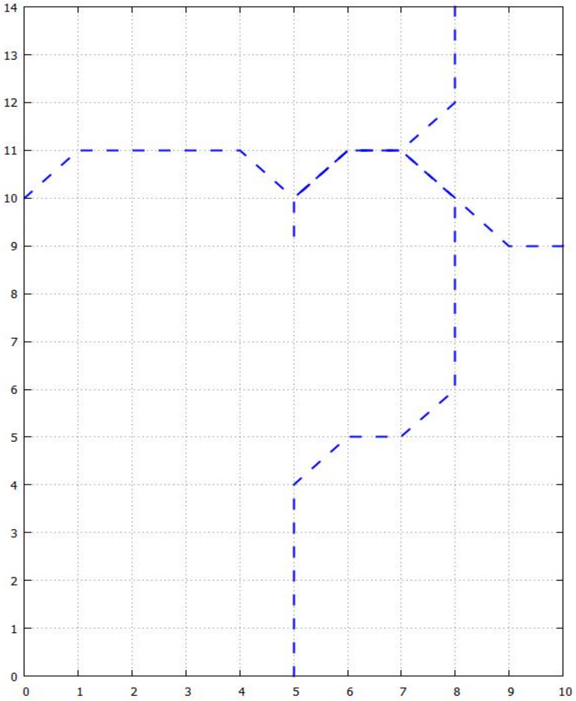
- Data: Stockholm Arlanda airport arrivals
- Data source: Opensky Network Database, BADA 4
- Average and high-traffic scenarios: 1 hour of operation
- Solved using GUROBI
- Run on a powerful Tetralith server, provided by SNIC, LIU: Intel HNS2600BPB nodes with 32 CPU cores and 384 GB RAM

Moderate traffic scenario: October 03, 2017

Tree 1: time: 15:00 - 15:30 (10 a/c)



Tree 2: time: 15:30 - 16:00 (7 a/c)



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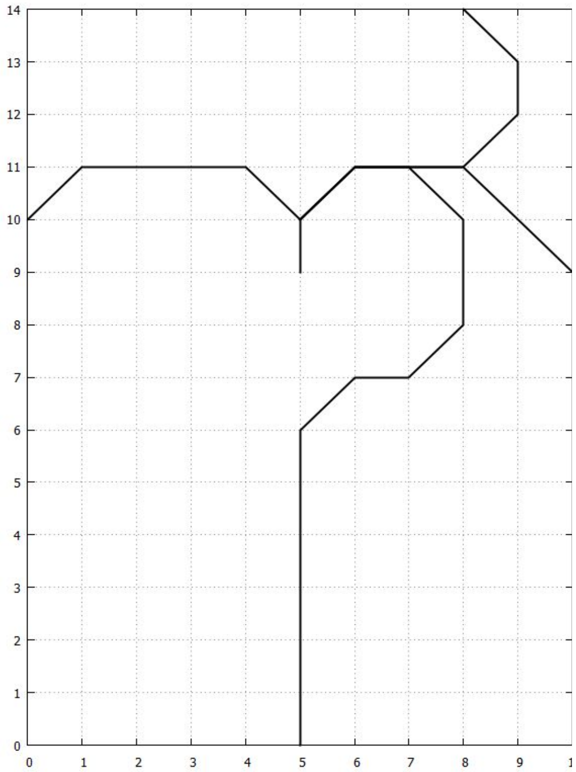

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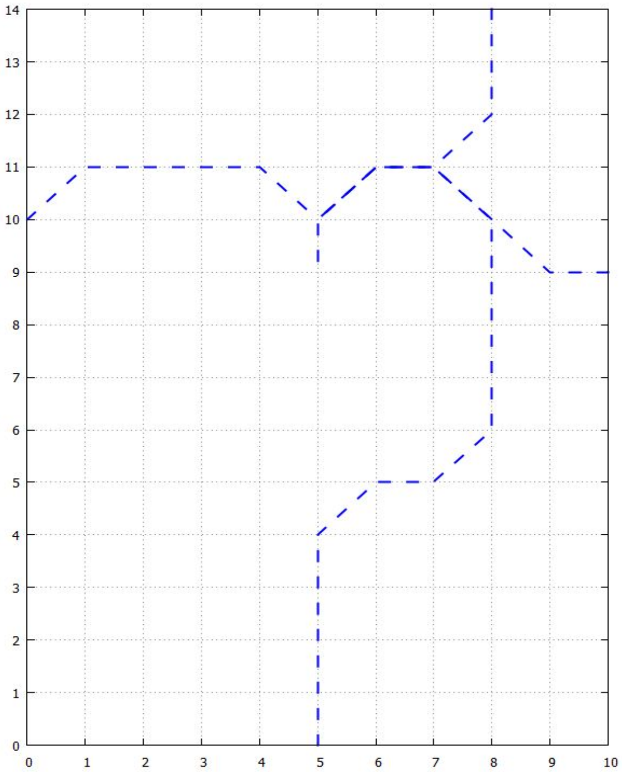

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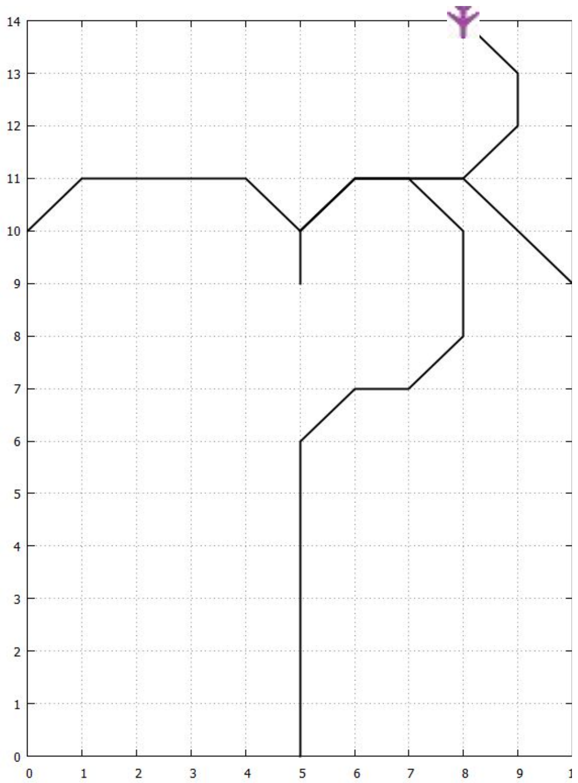

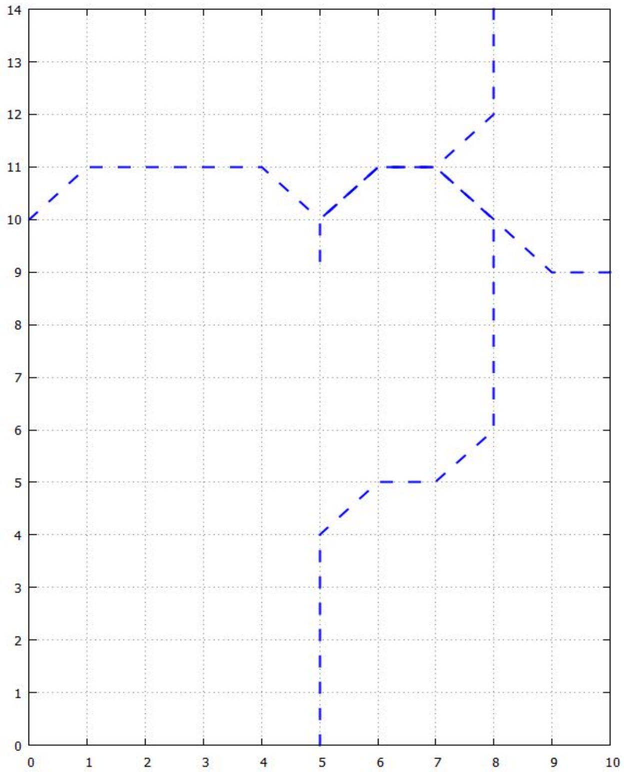

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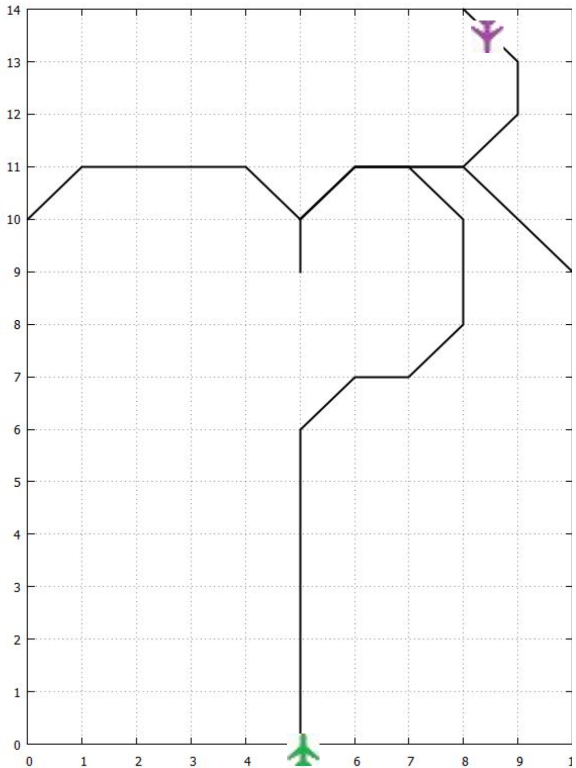
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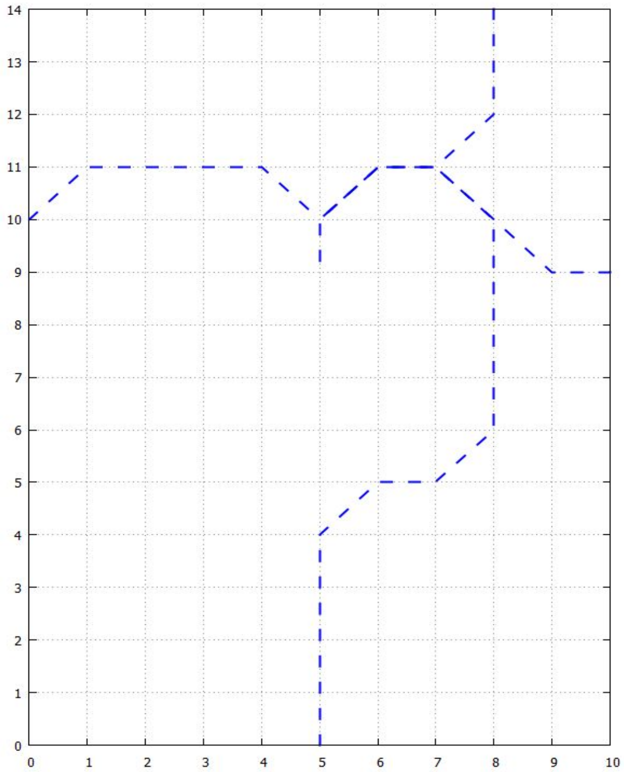
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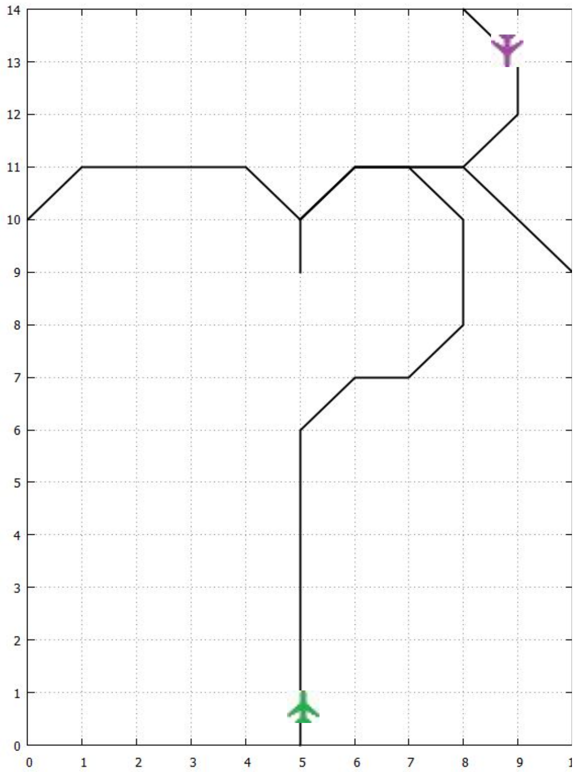

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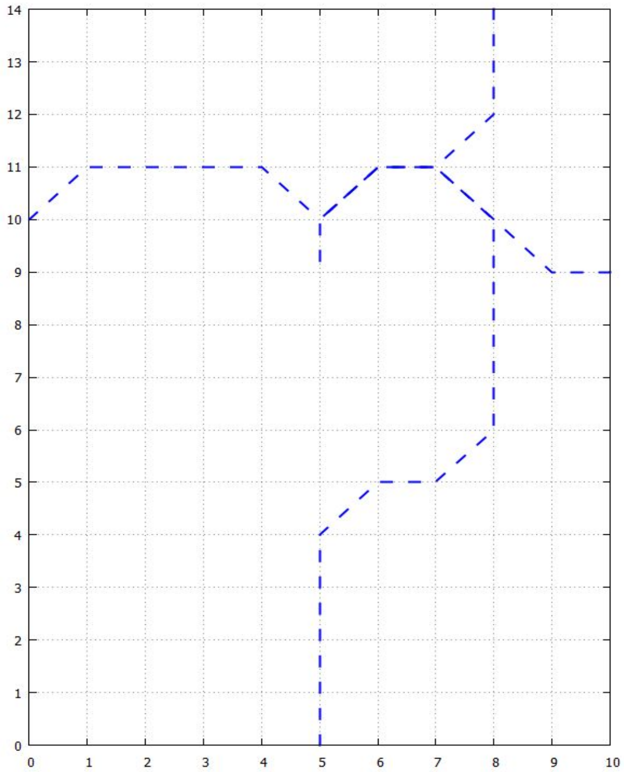

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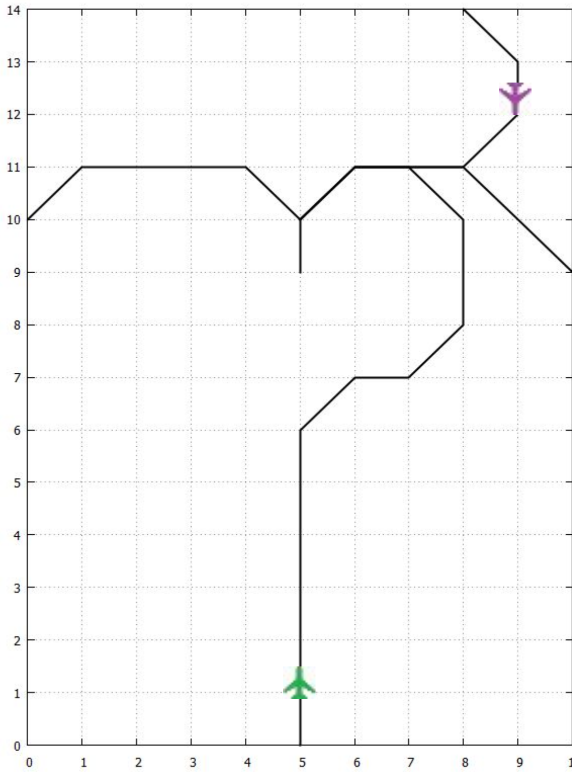

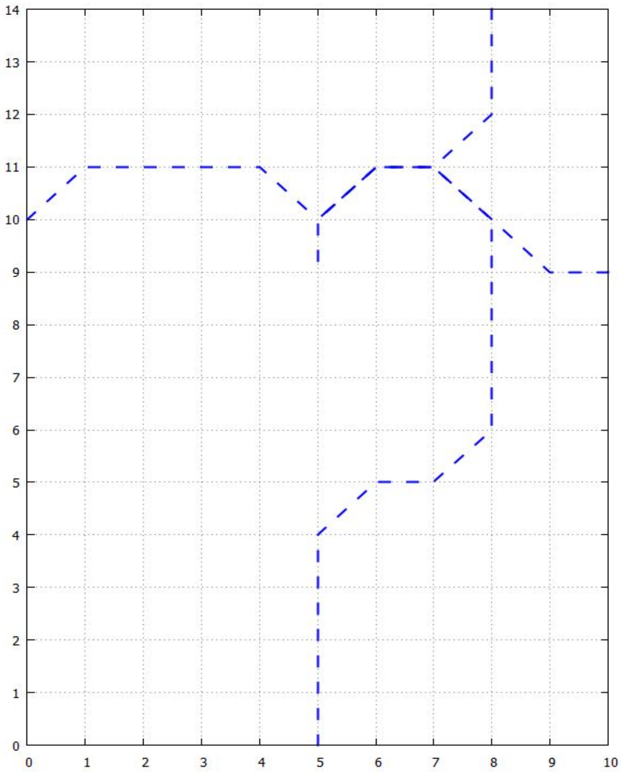

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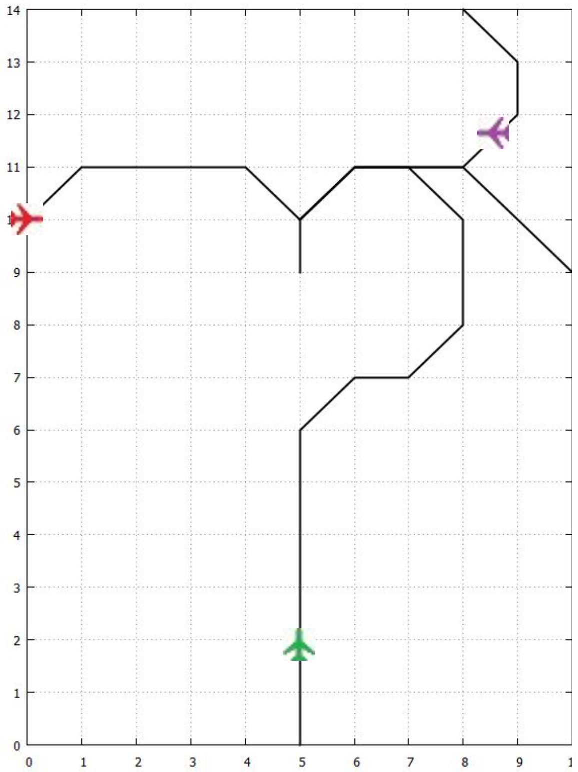
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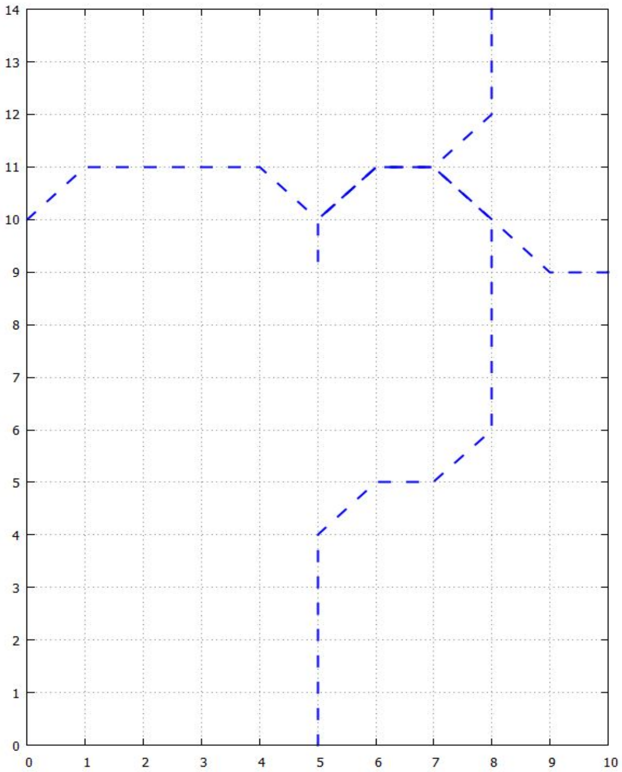
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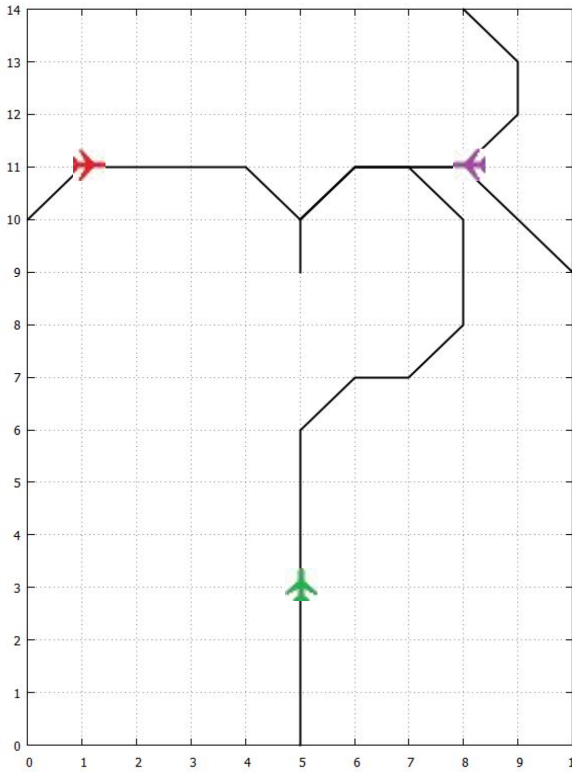

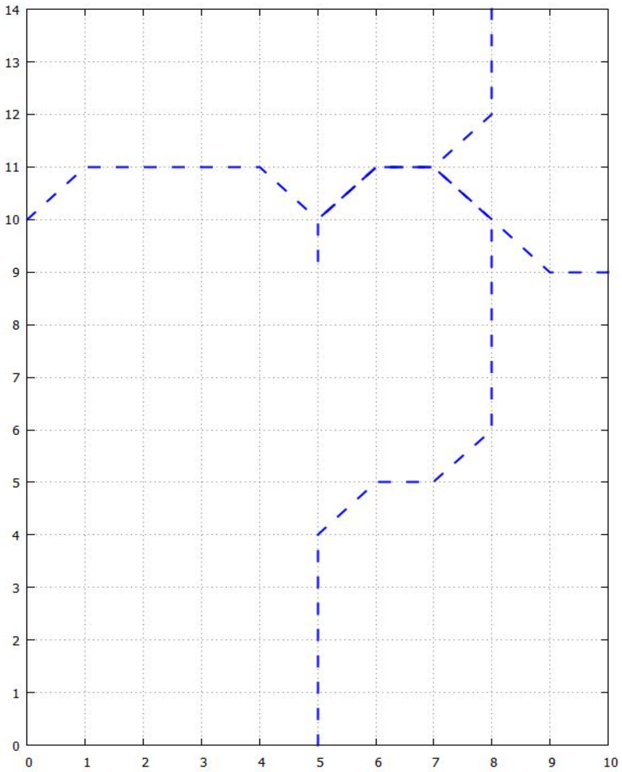

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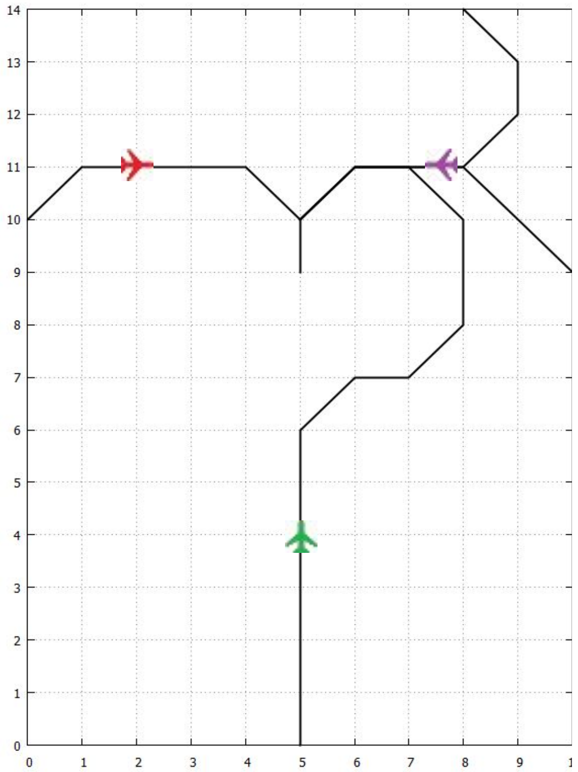

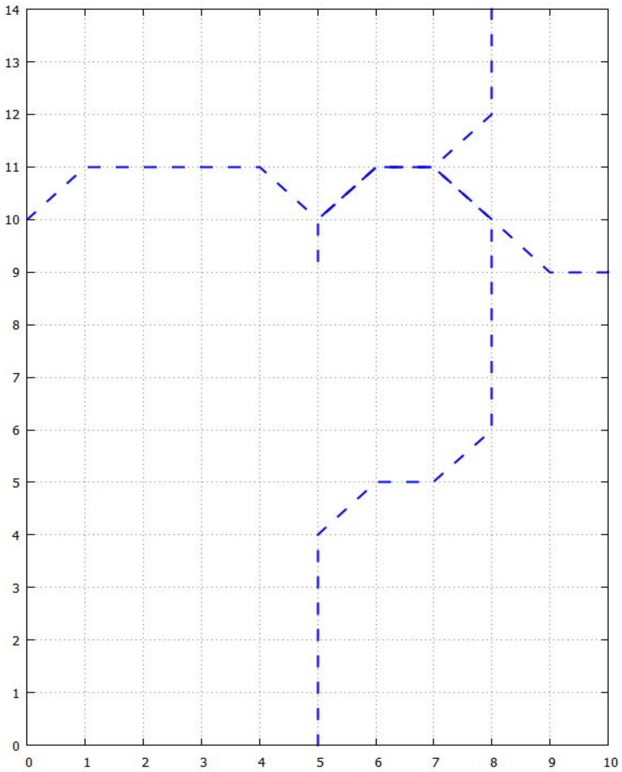

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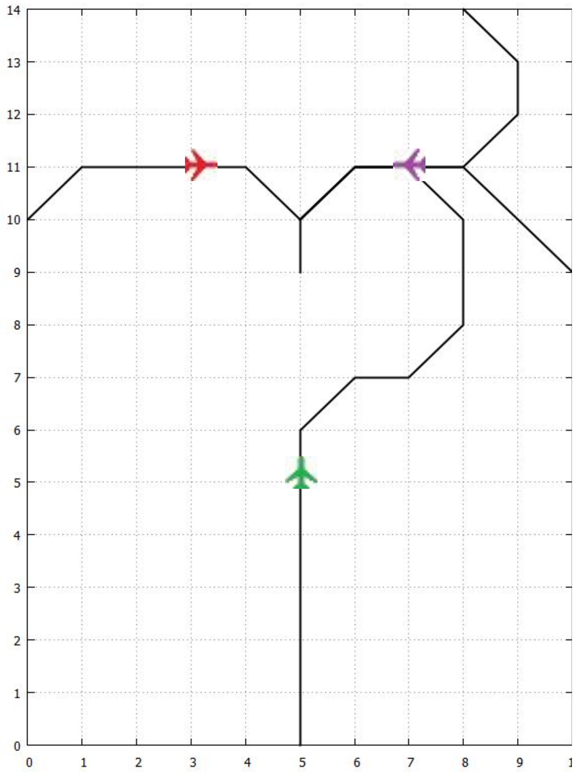

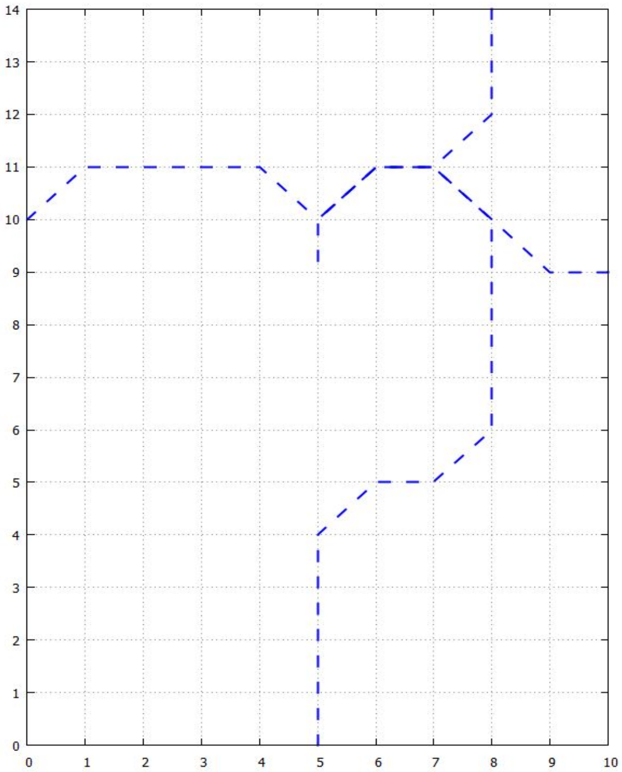

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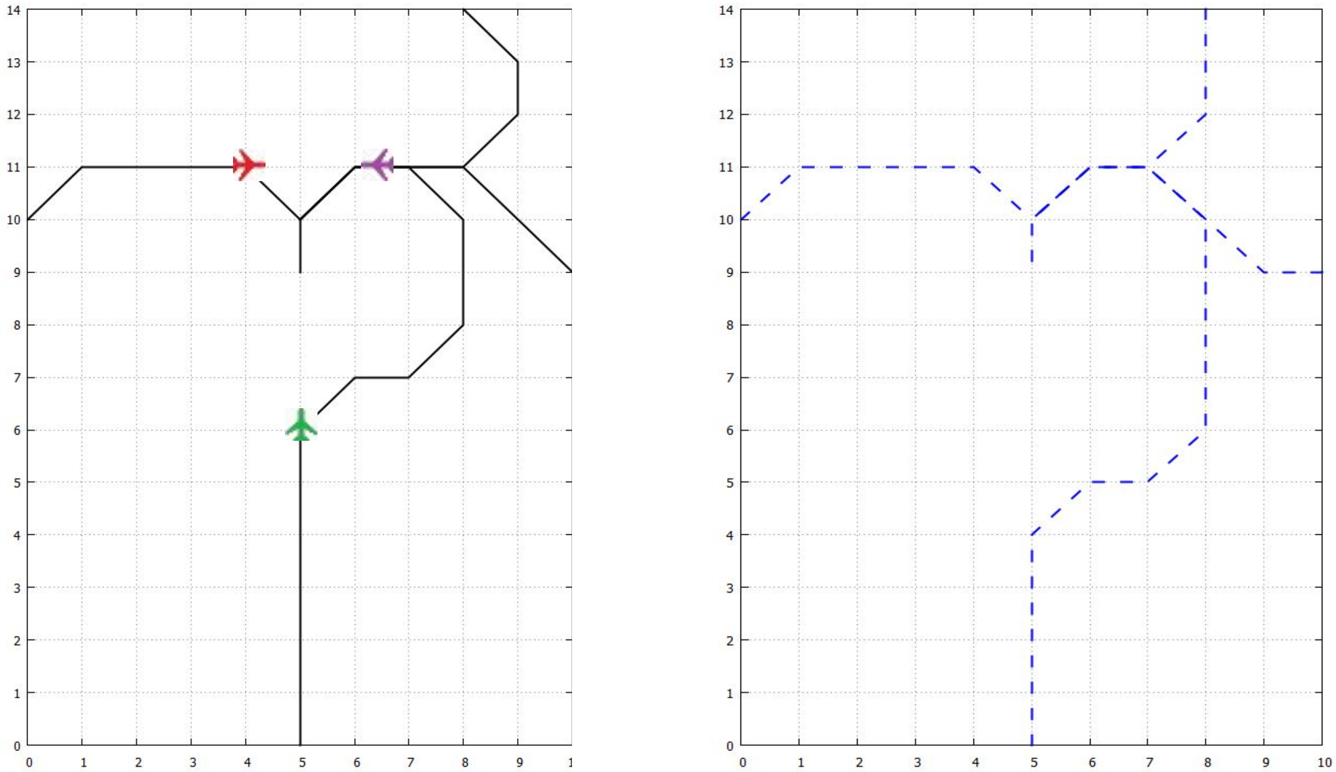

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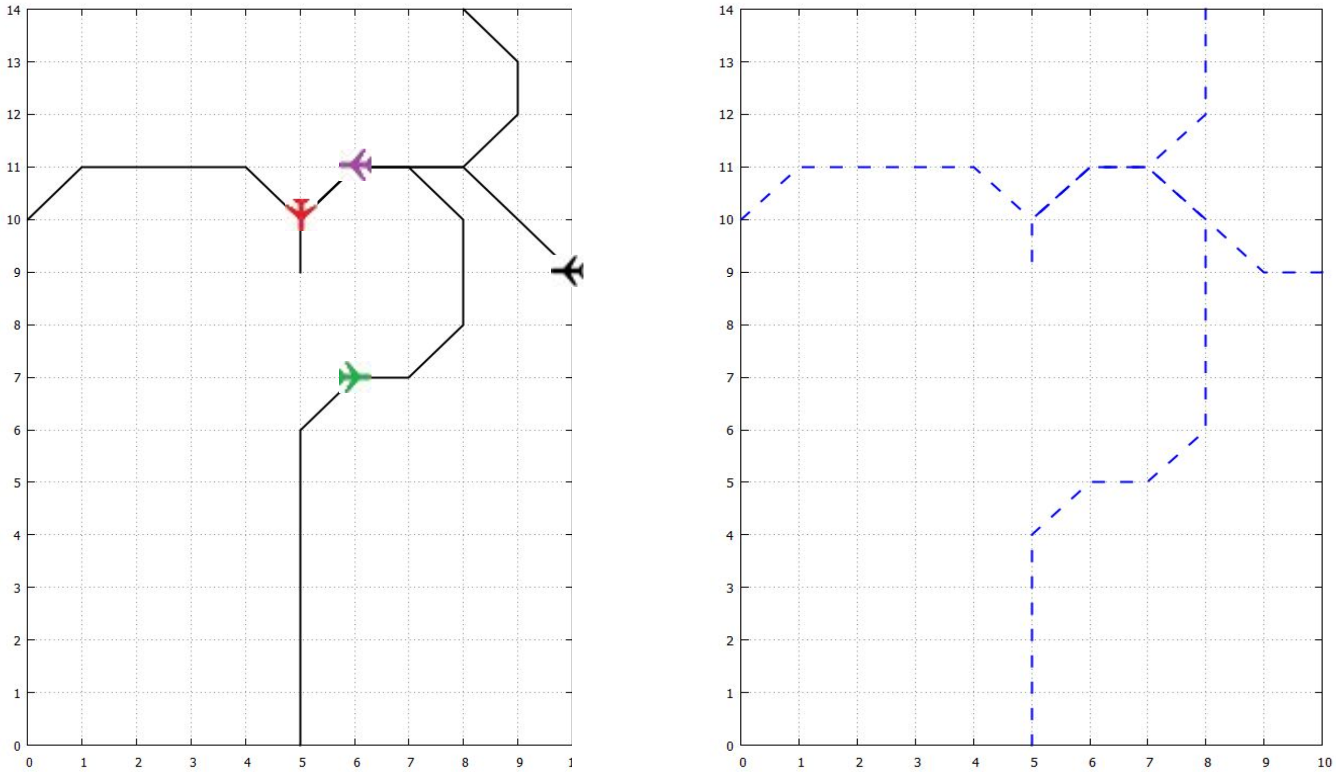

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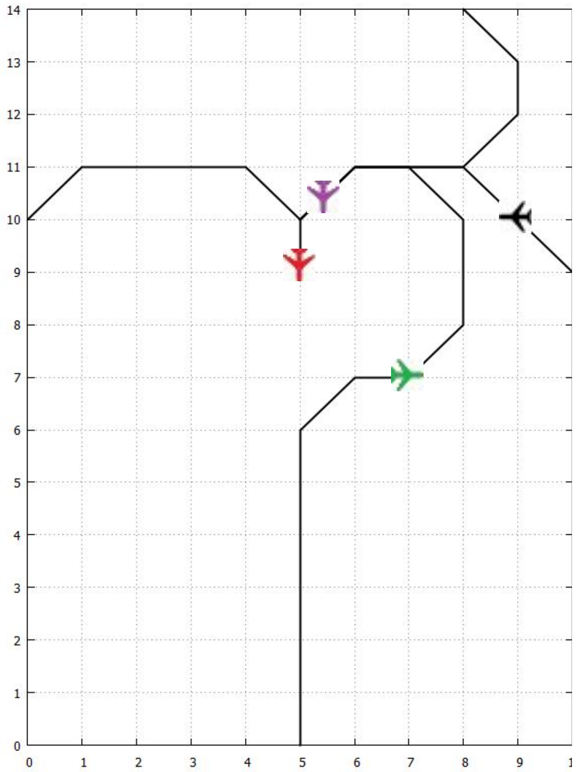

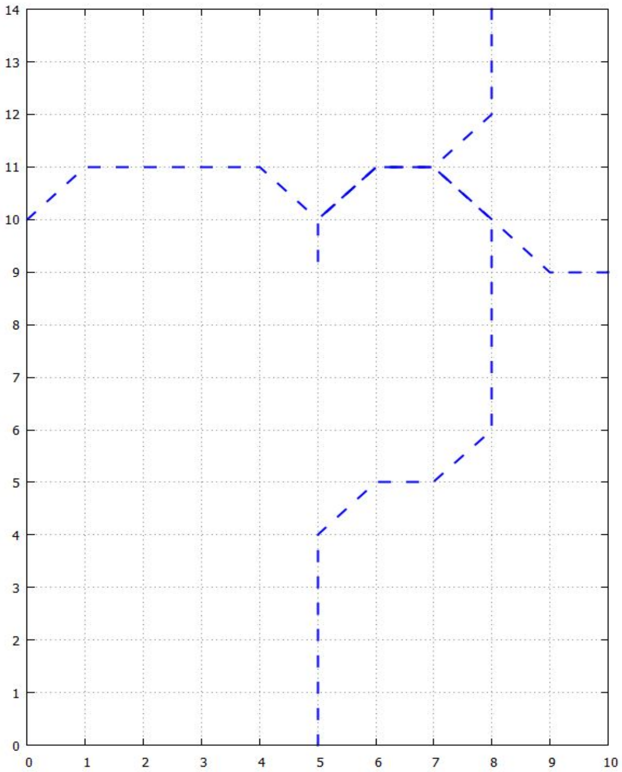

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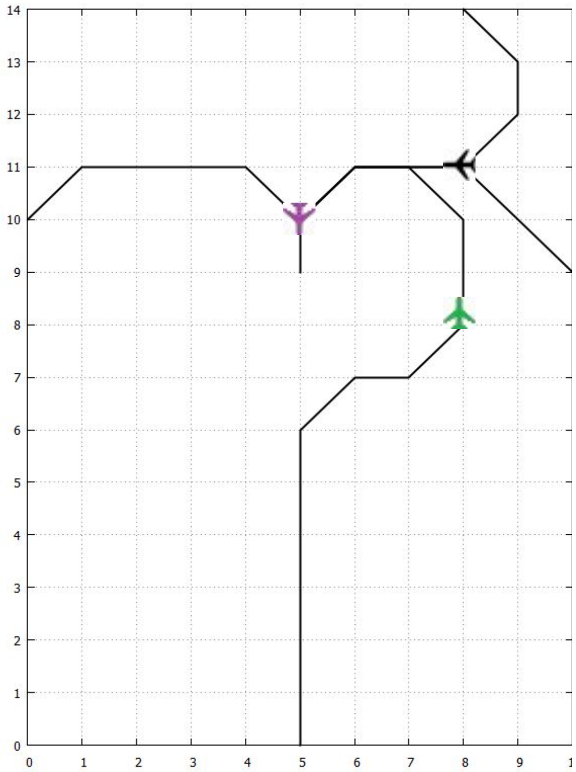
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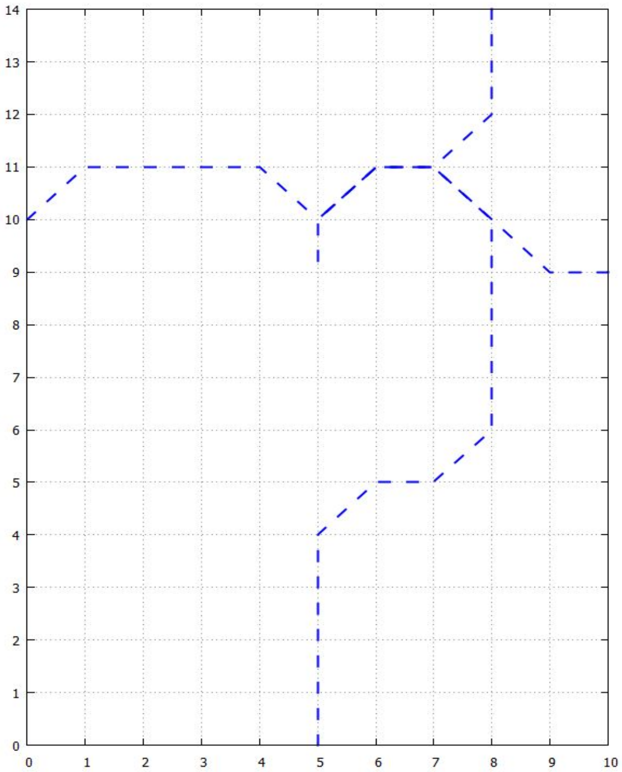
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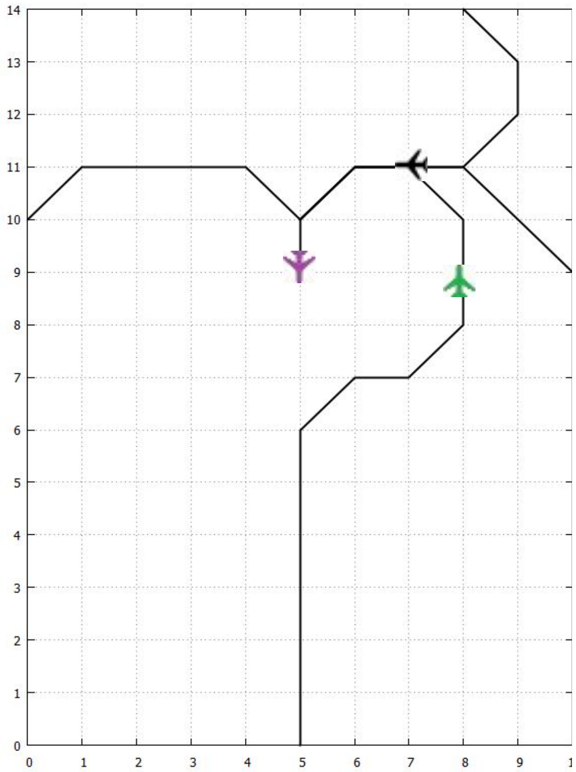
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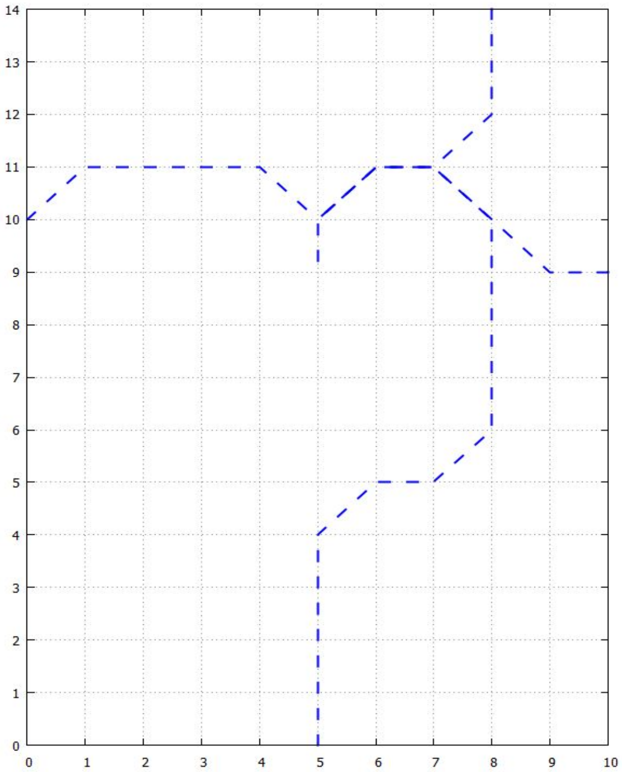
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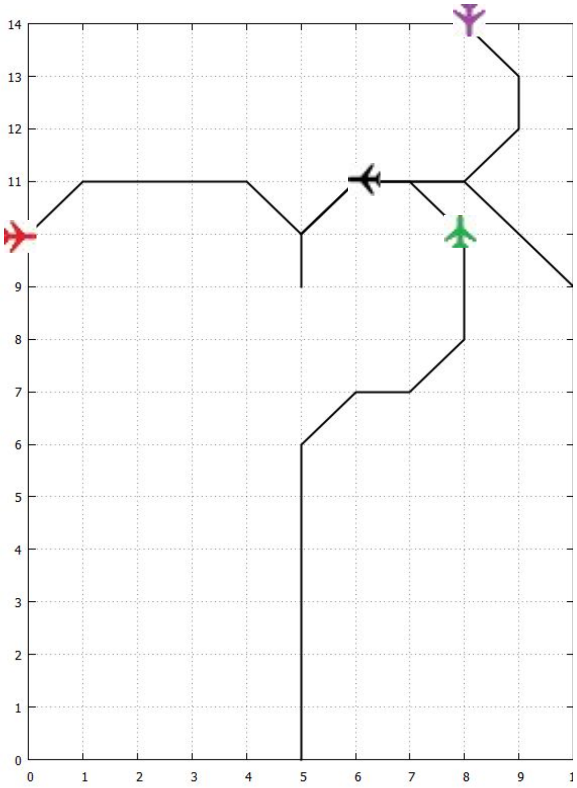
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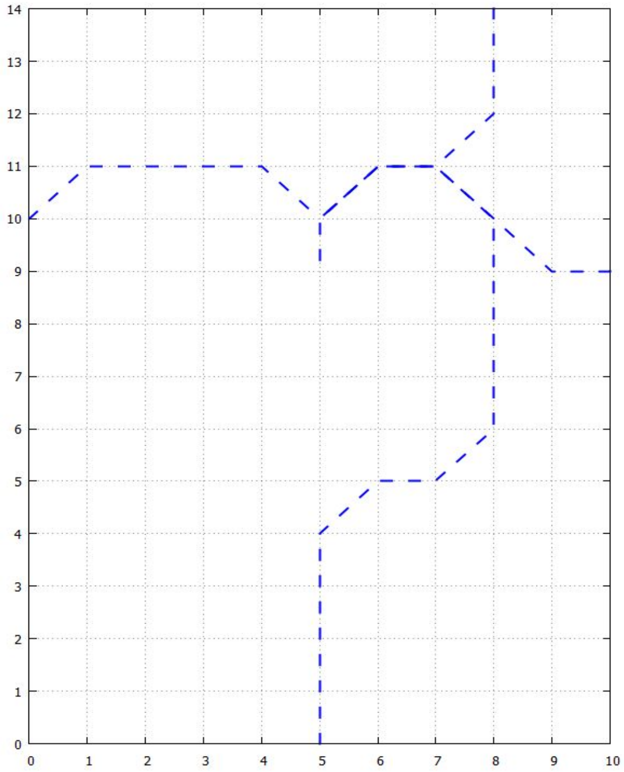
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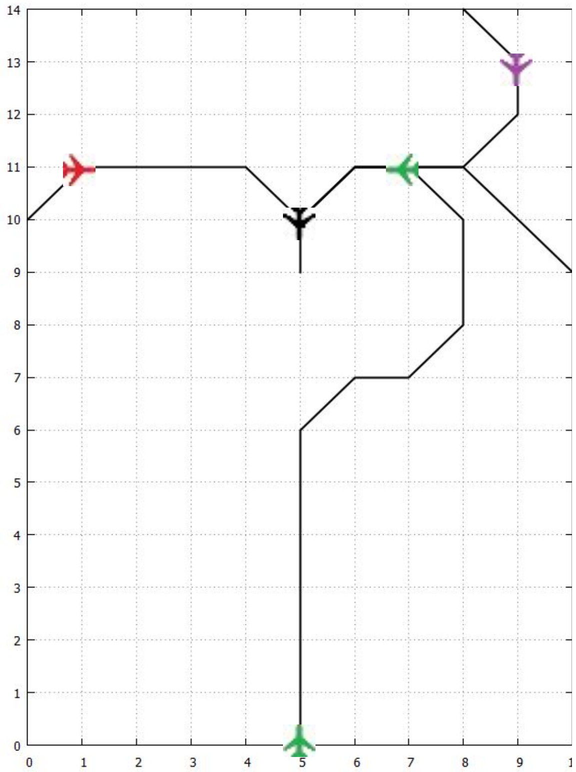

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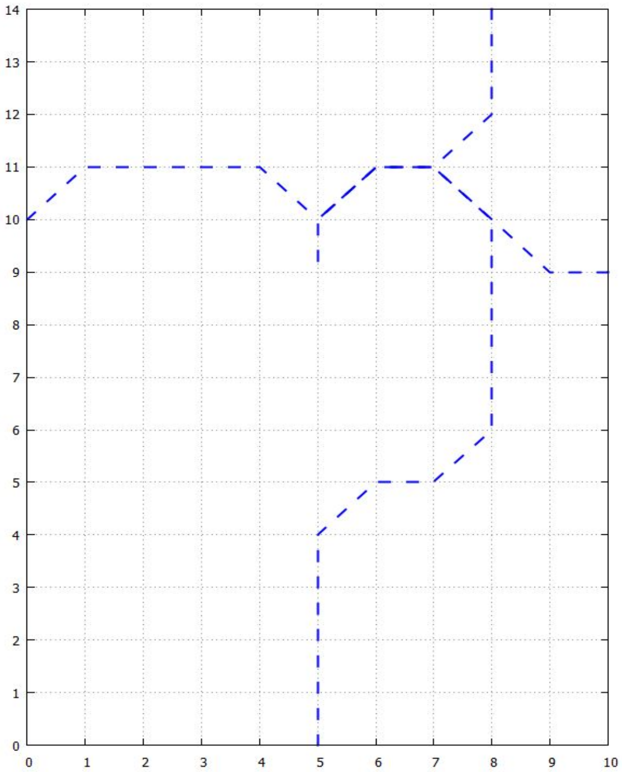

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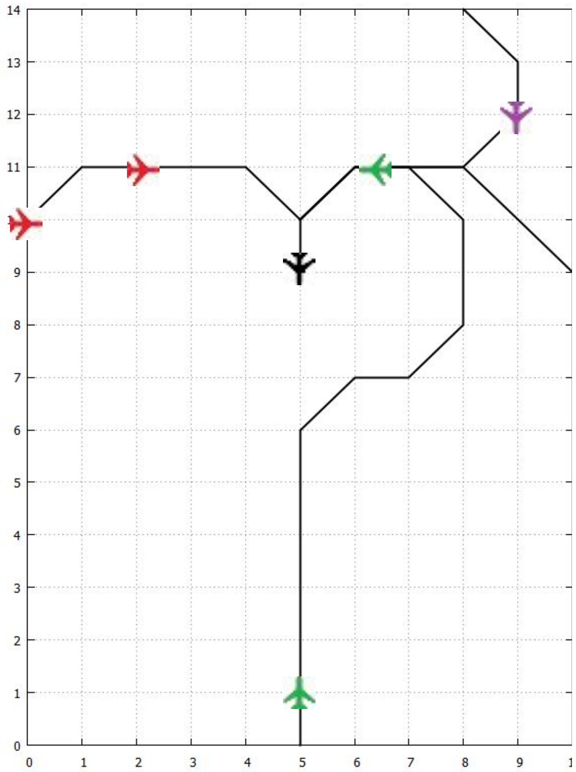
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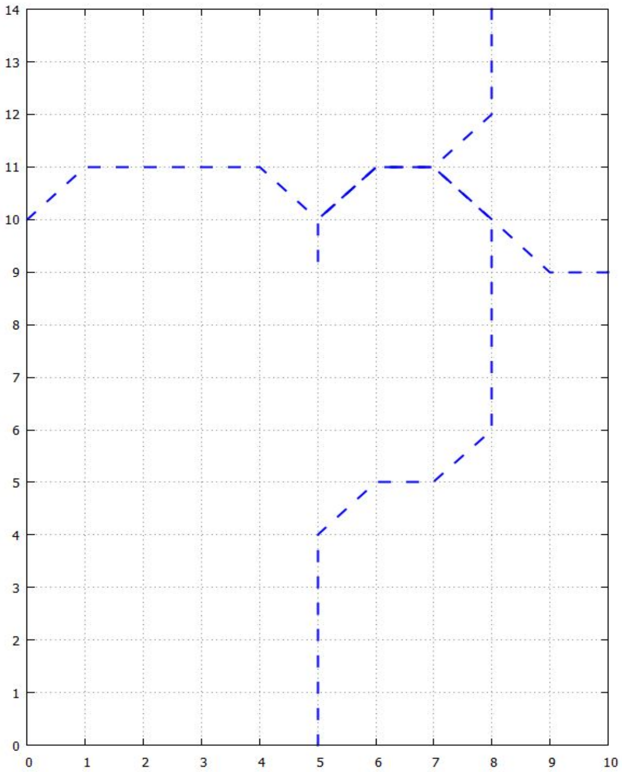
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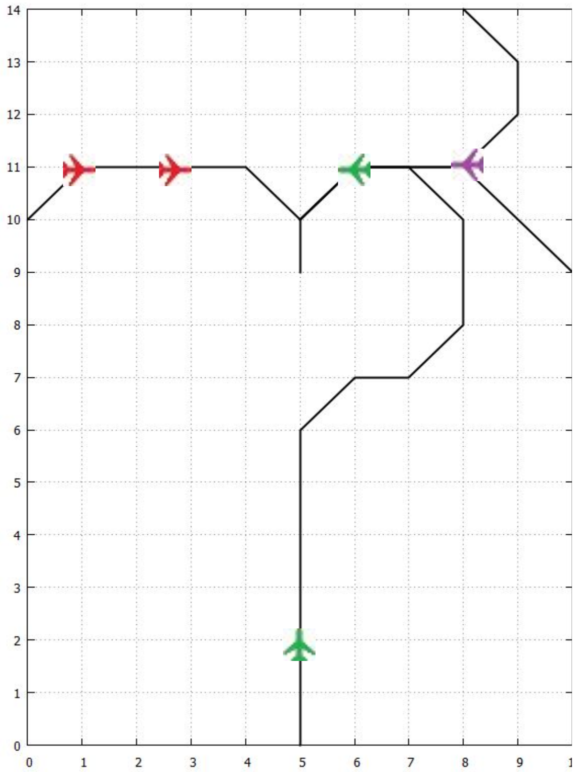
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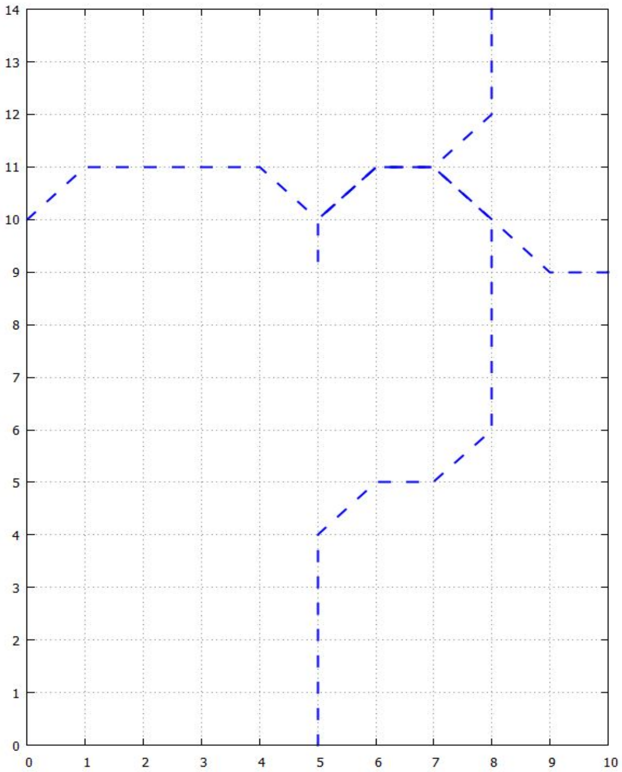
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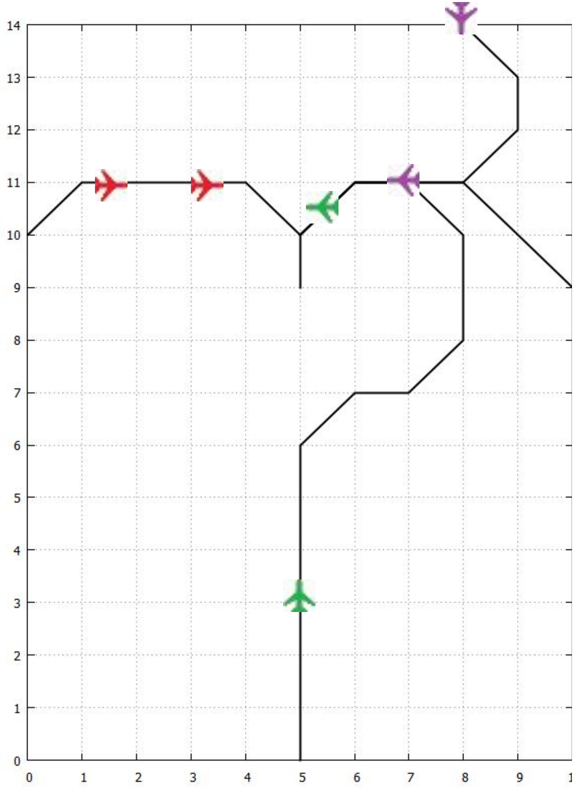

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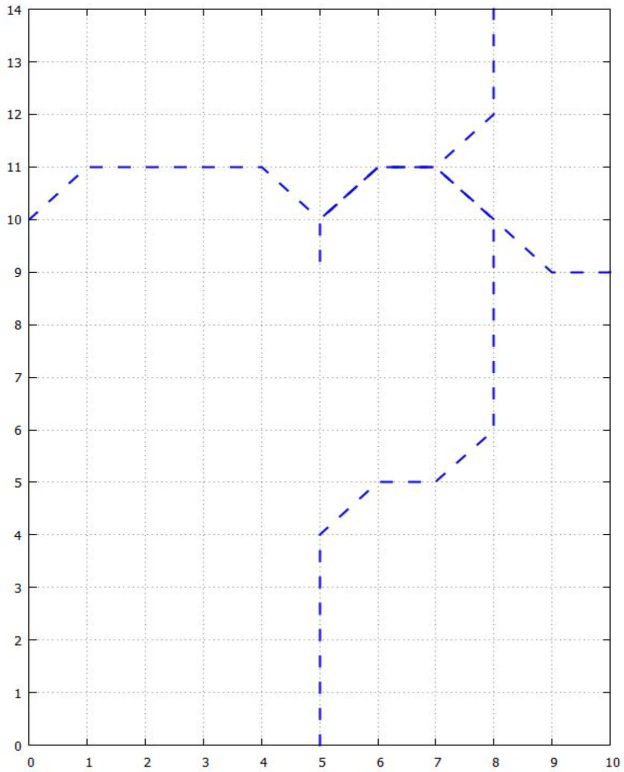

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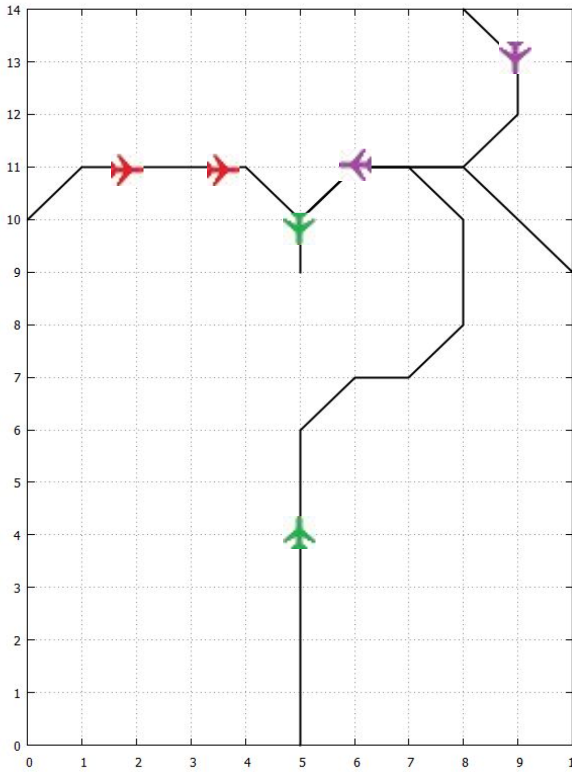
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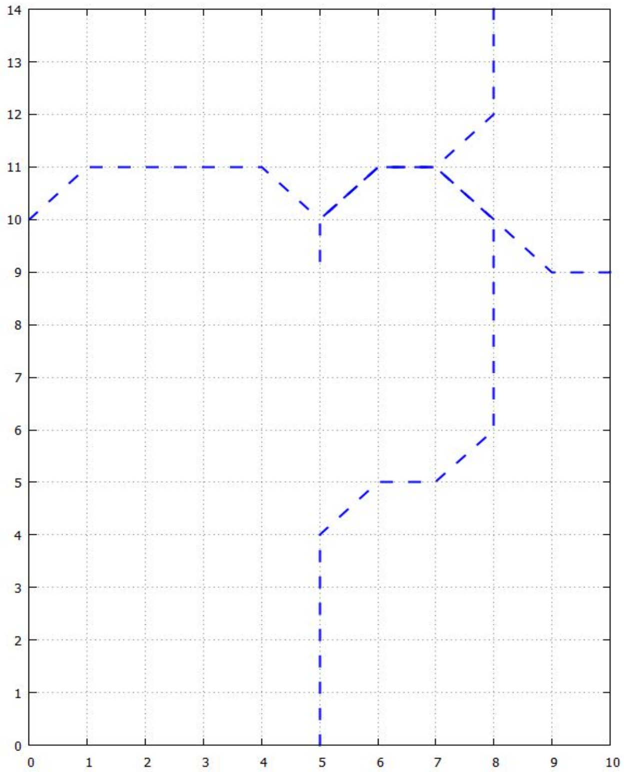
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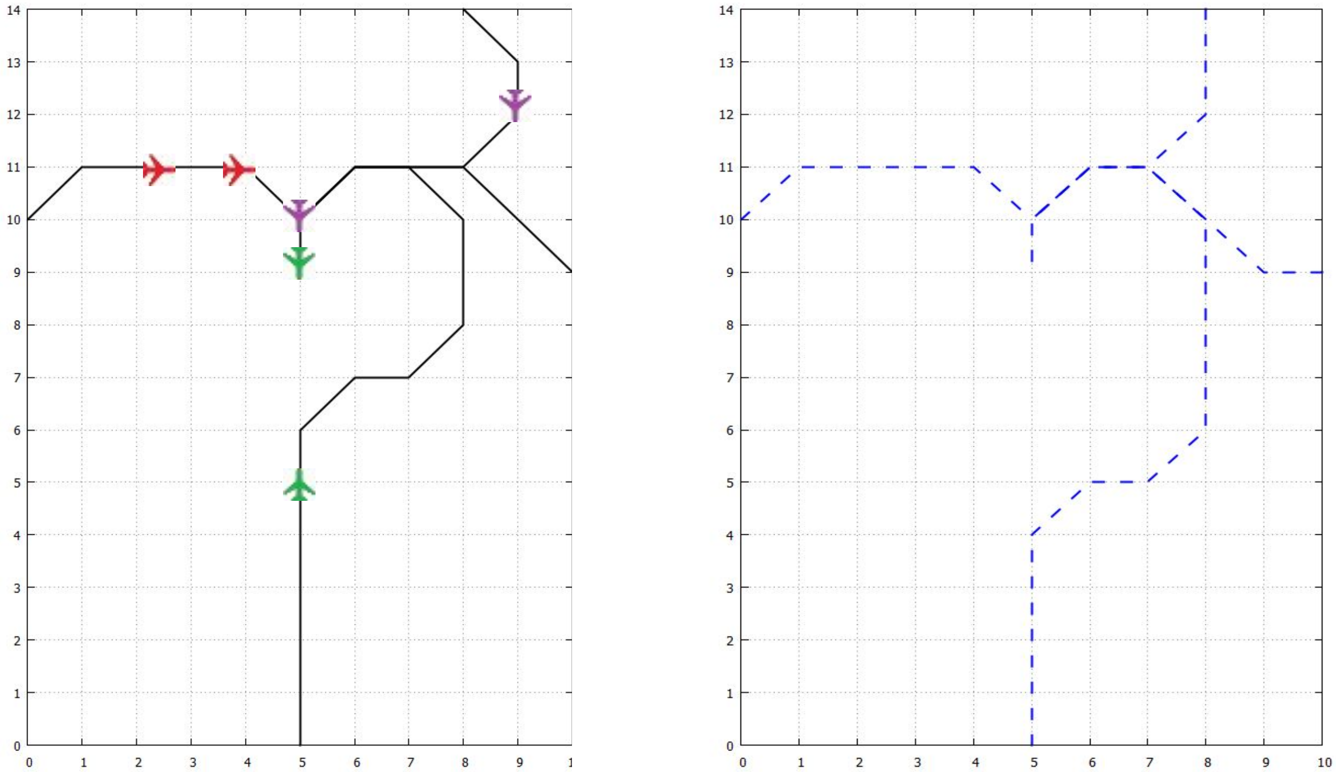

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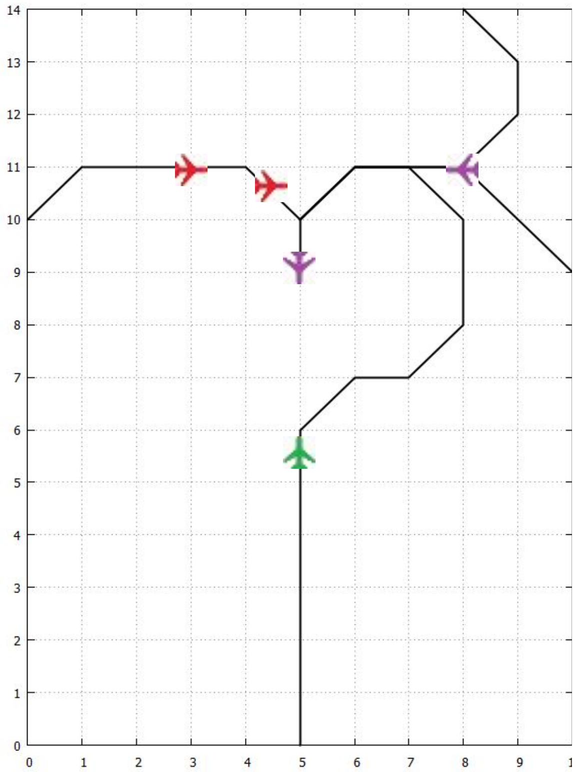
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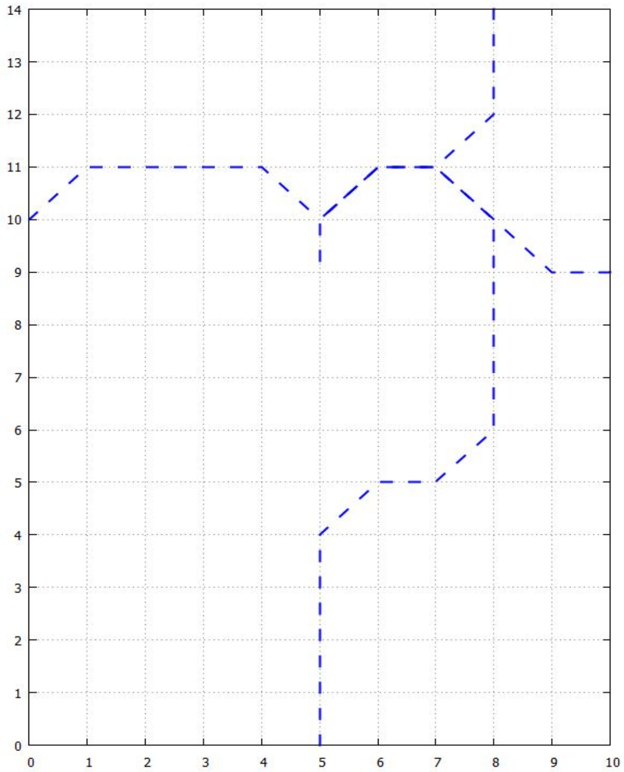
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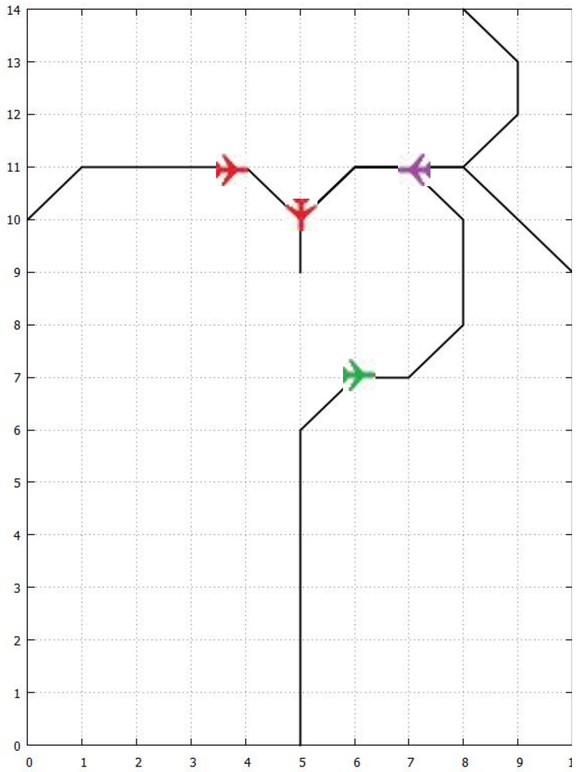
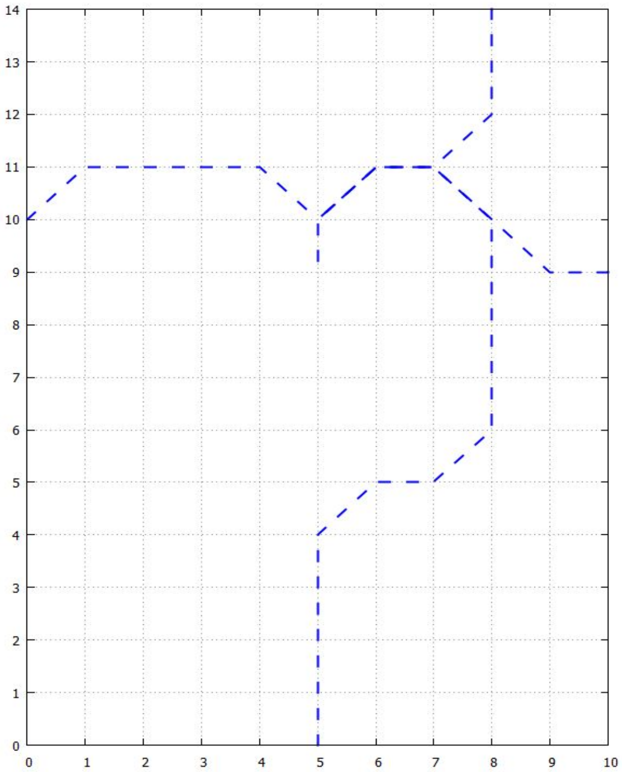
t = 15:25





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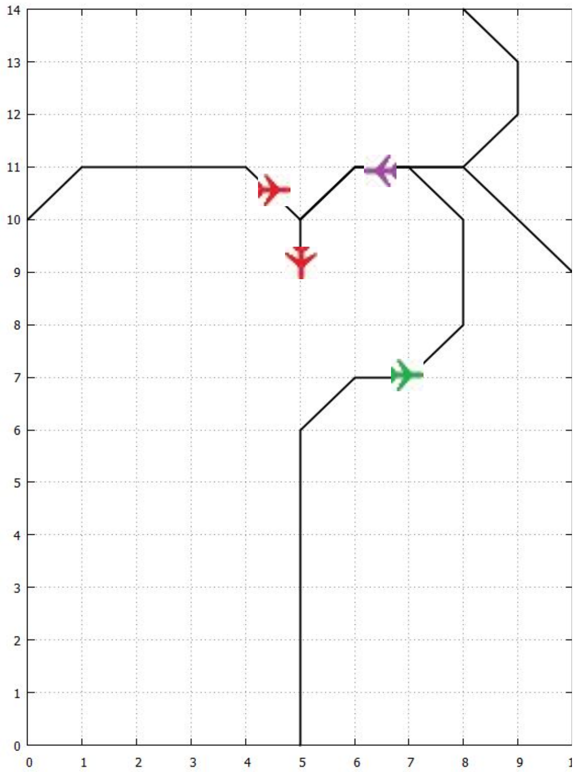
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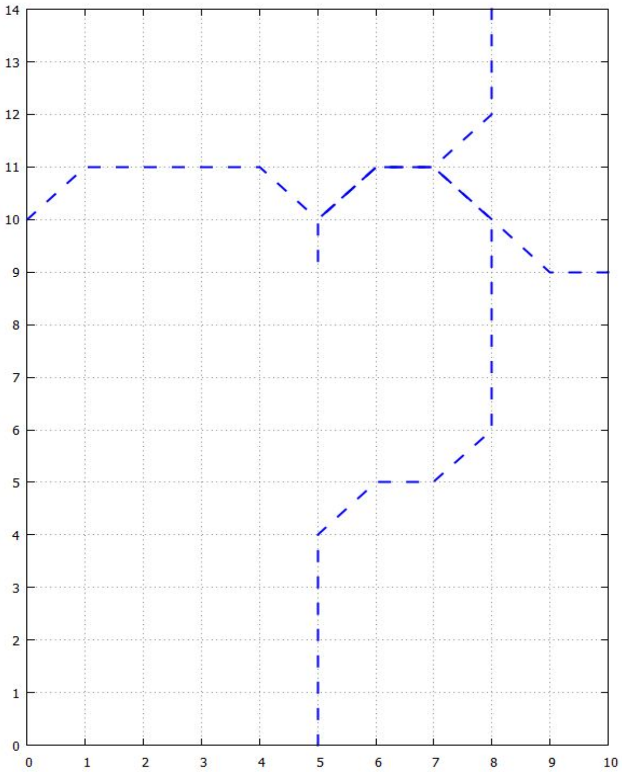
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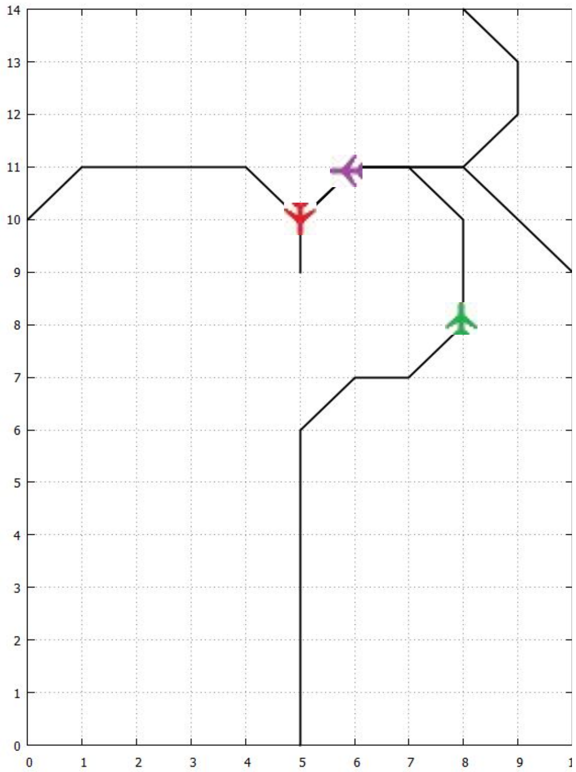
t = 15:27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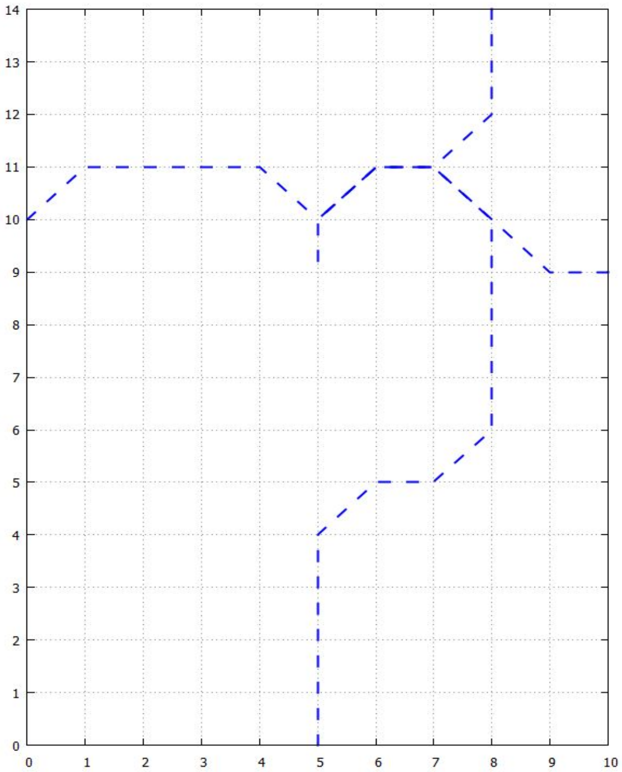
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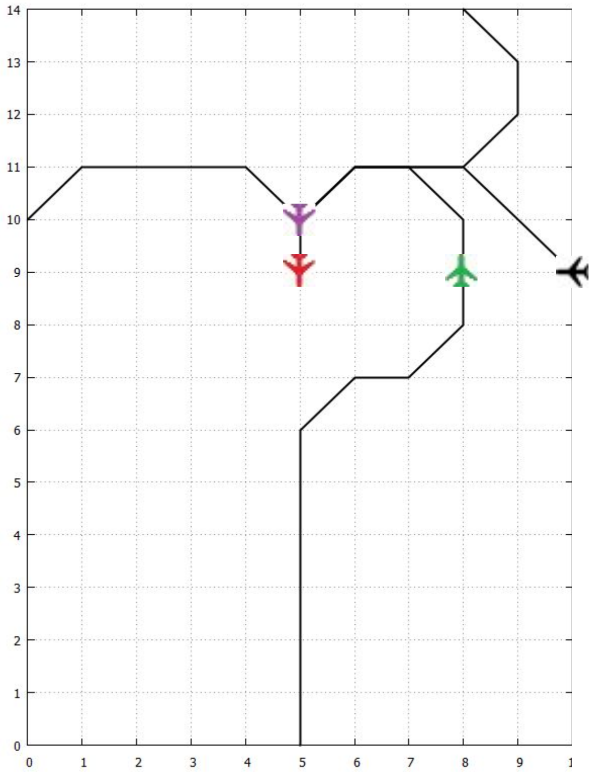
t = 15:28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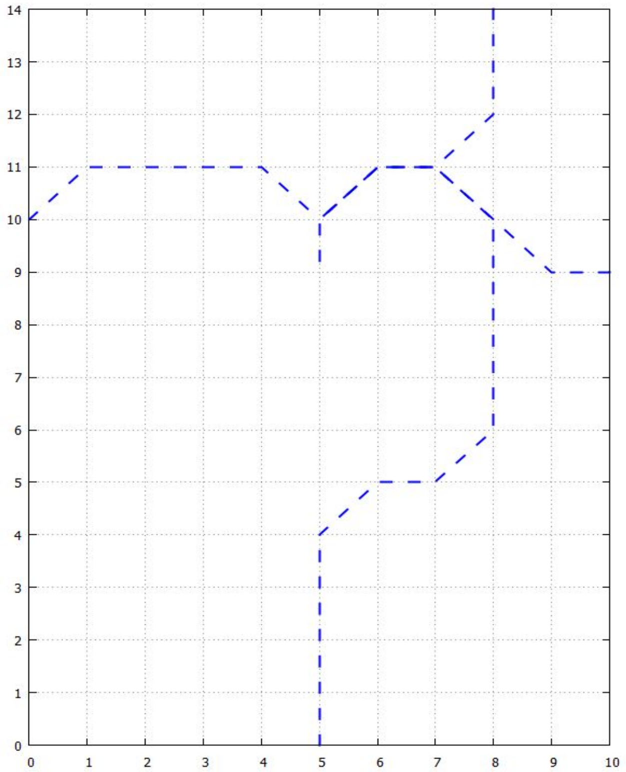
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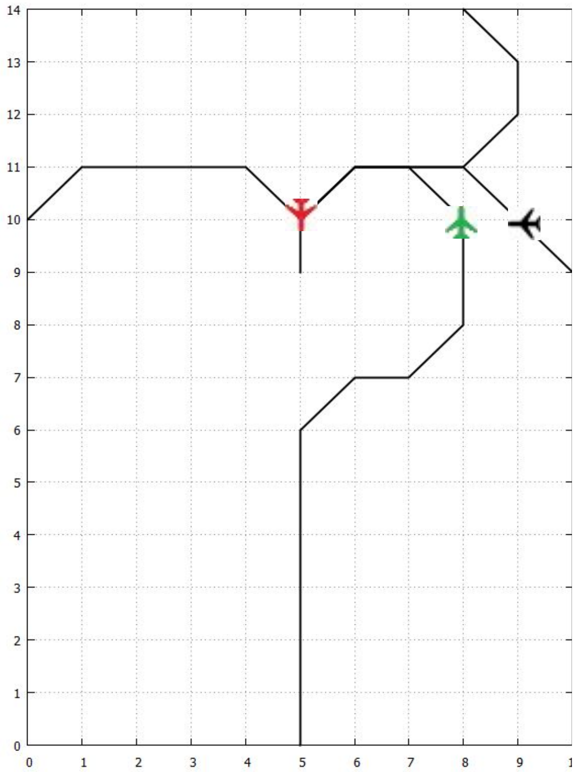
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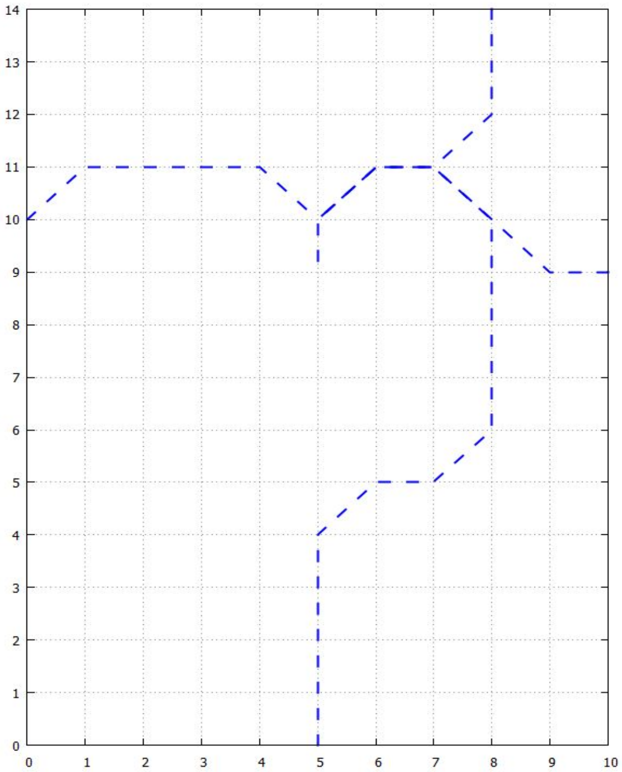
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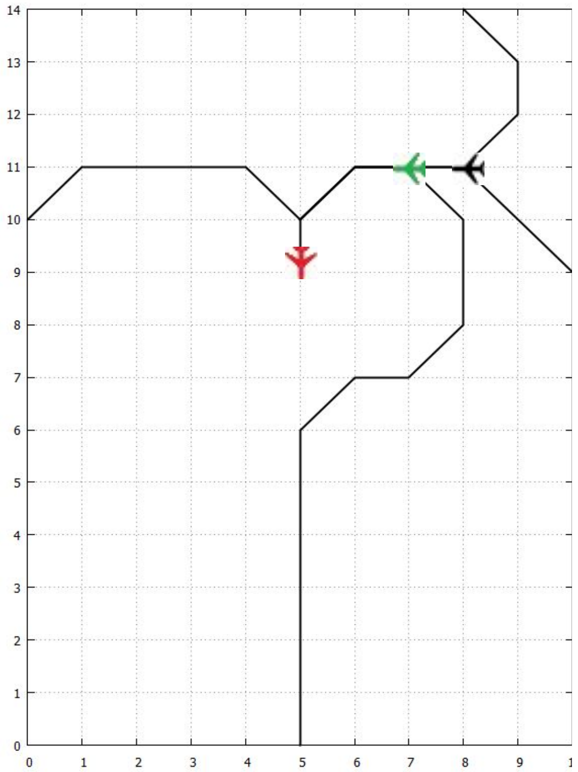
t = 15:30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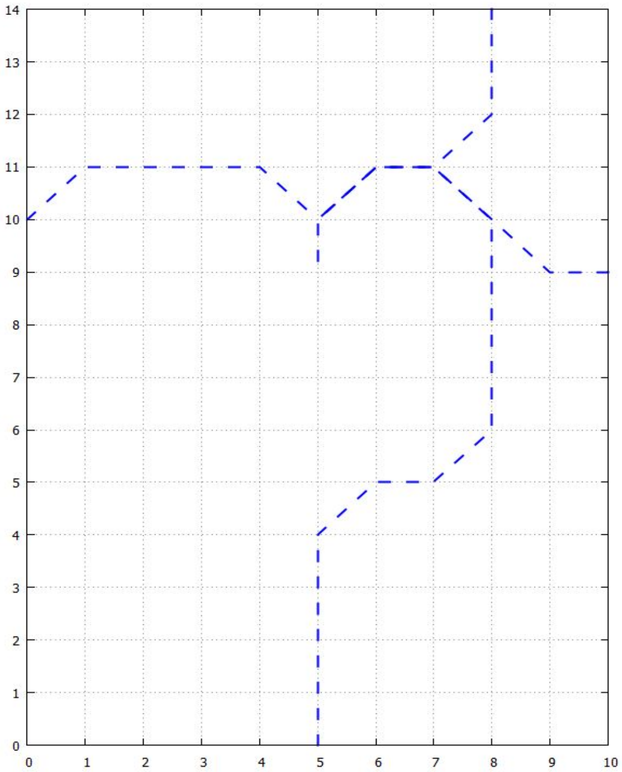
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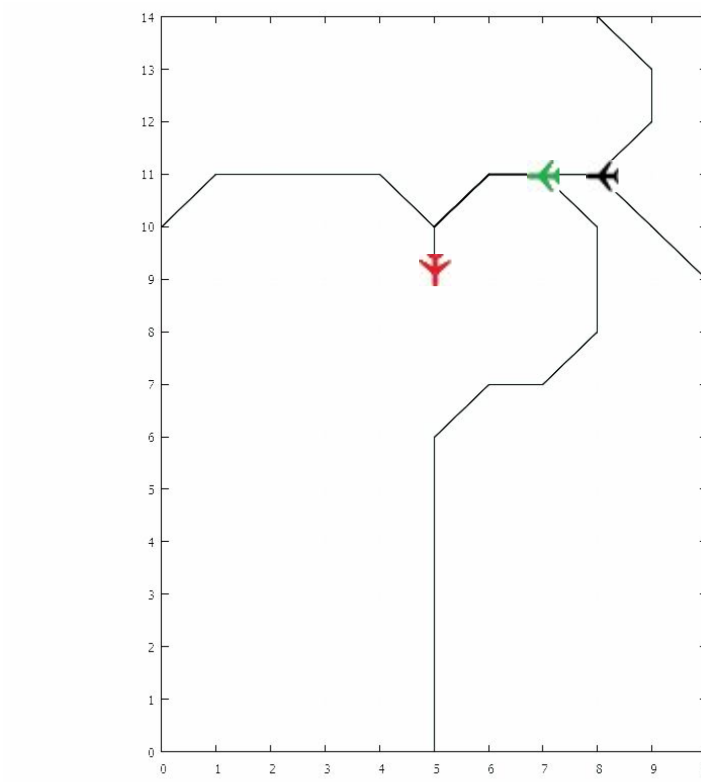
t = 15:30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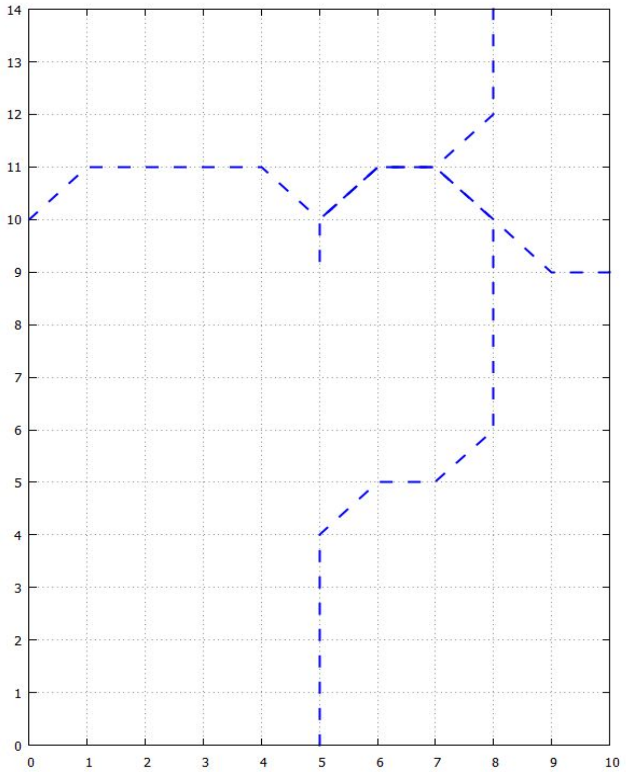
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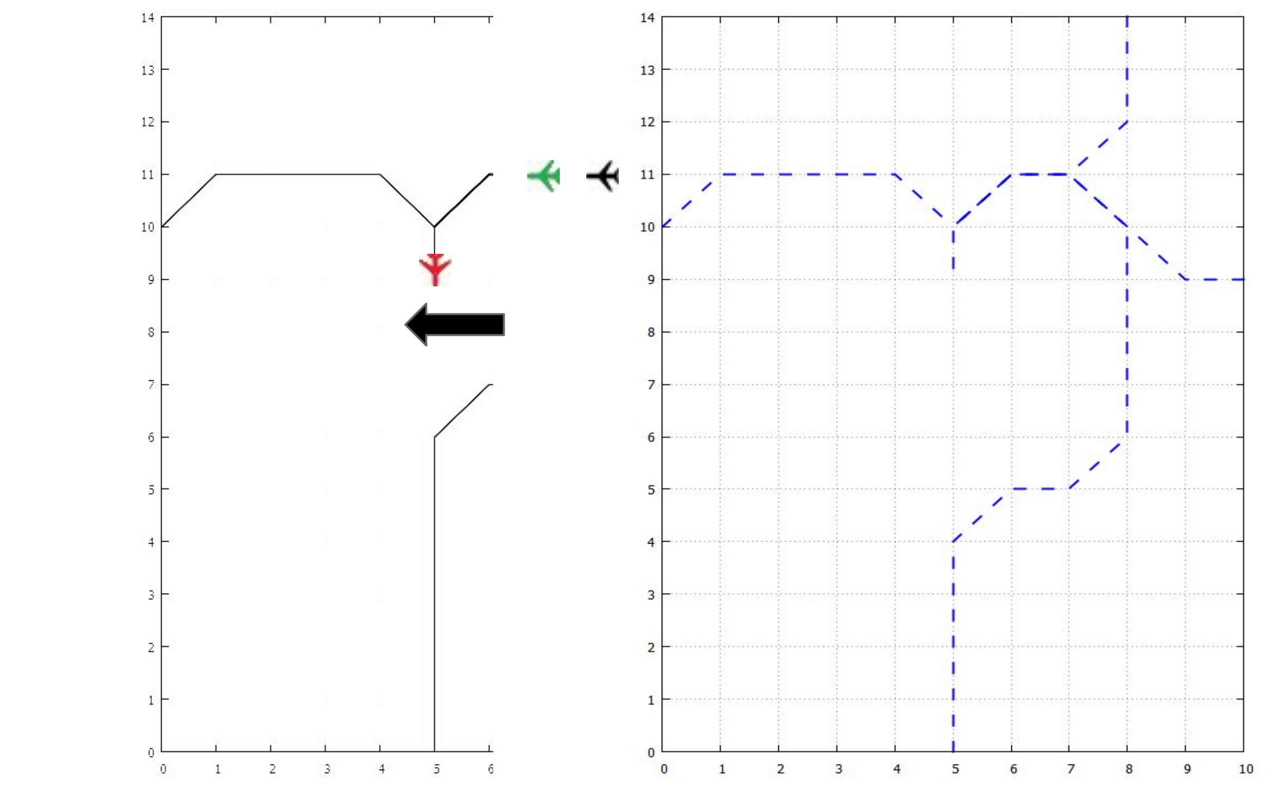
t = 15:30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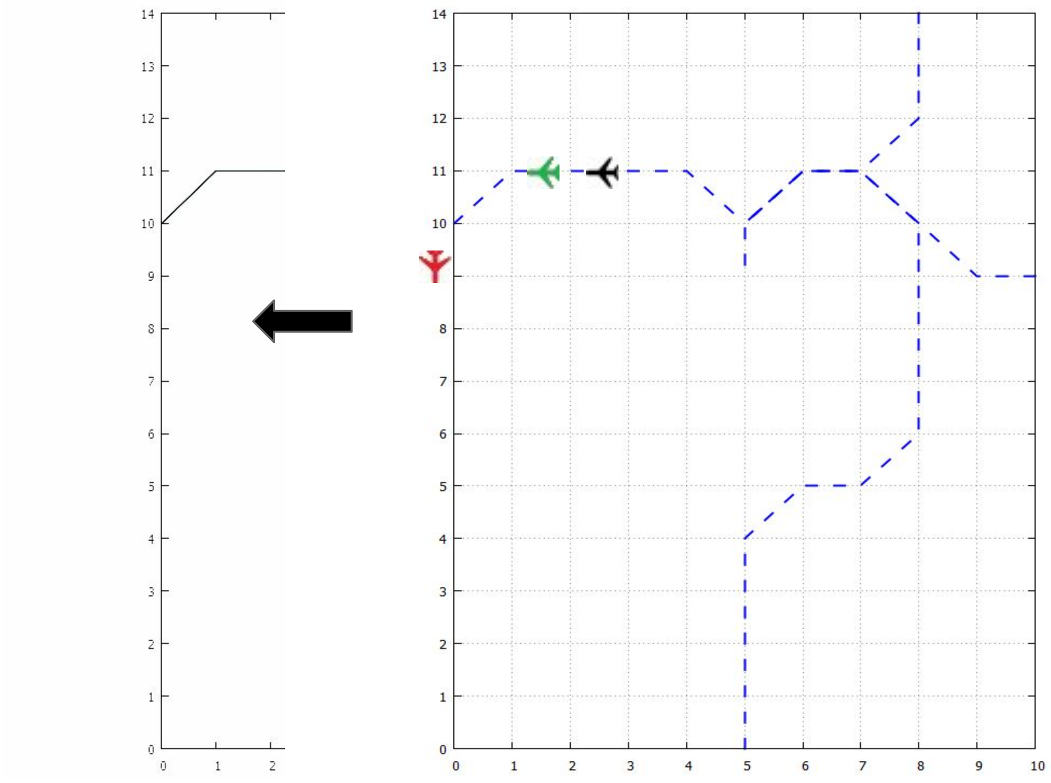
t = 15:30



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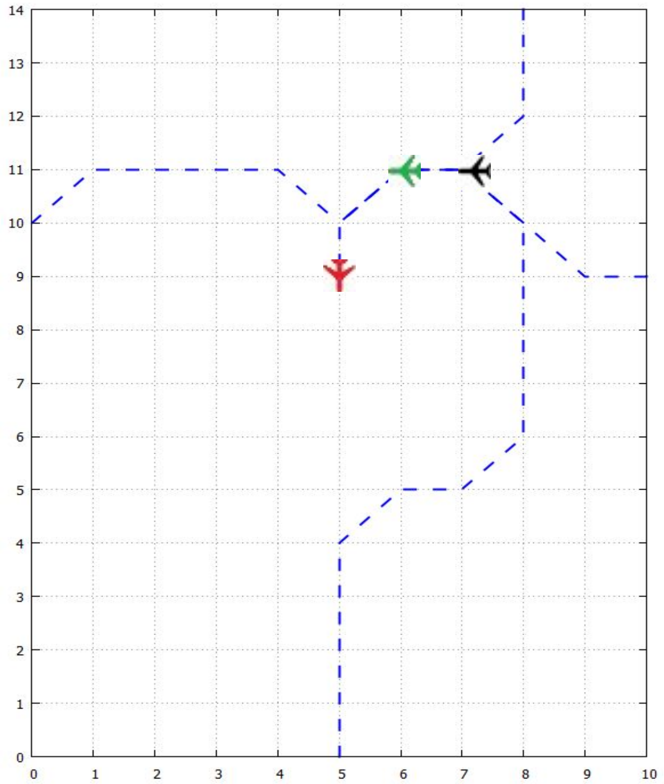

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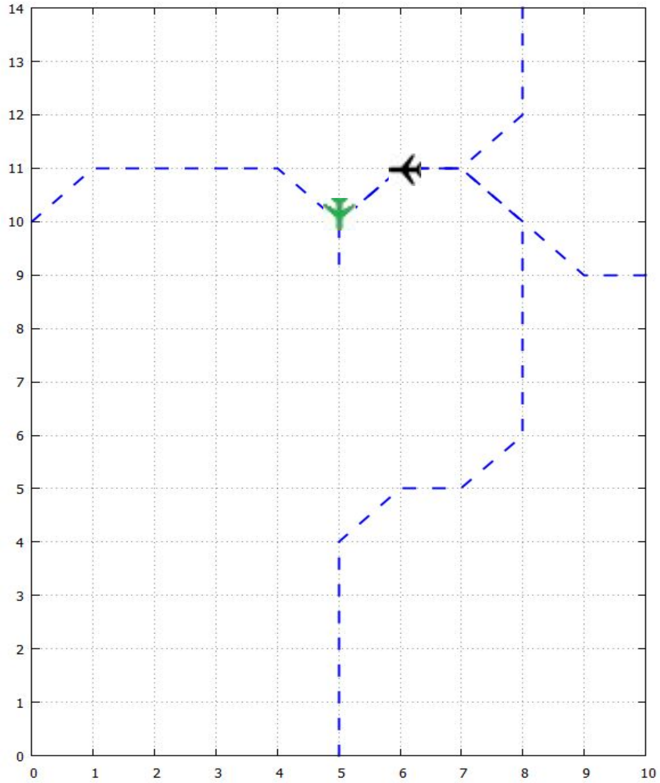

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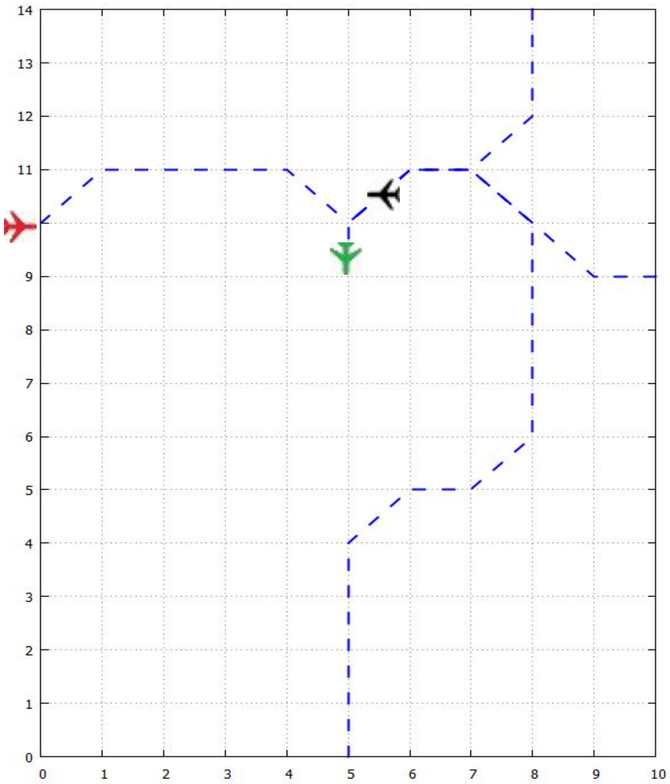
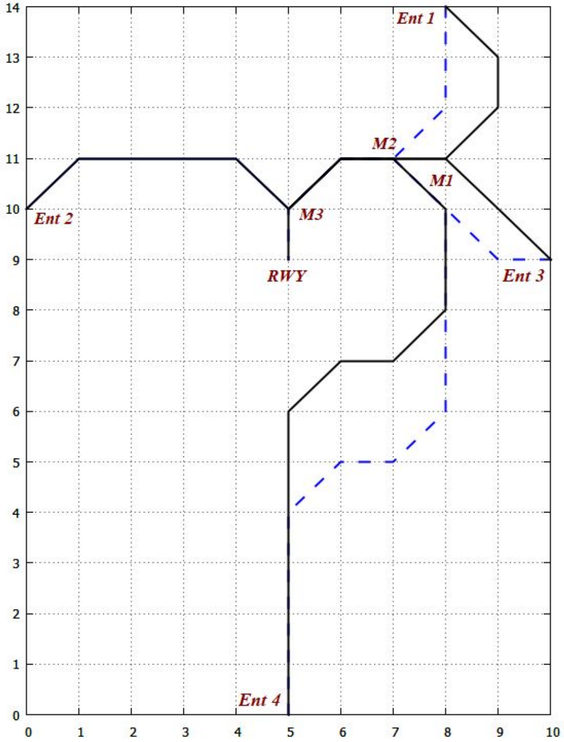


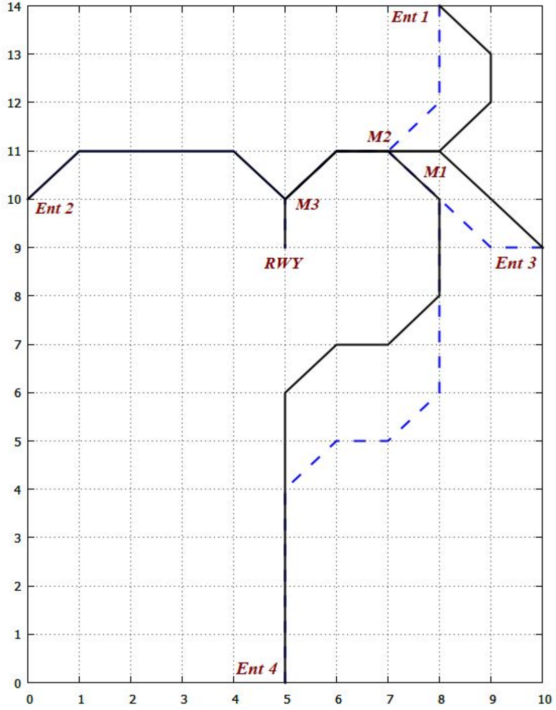
Moderate traffic scenario: October 03, 2017

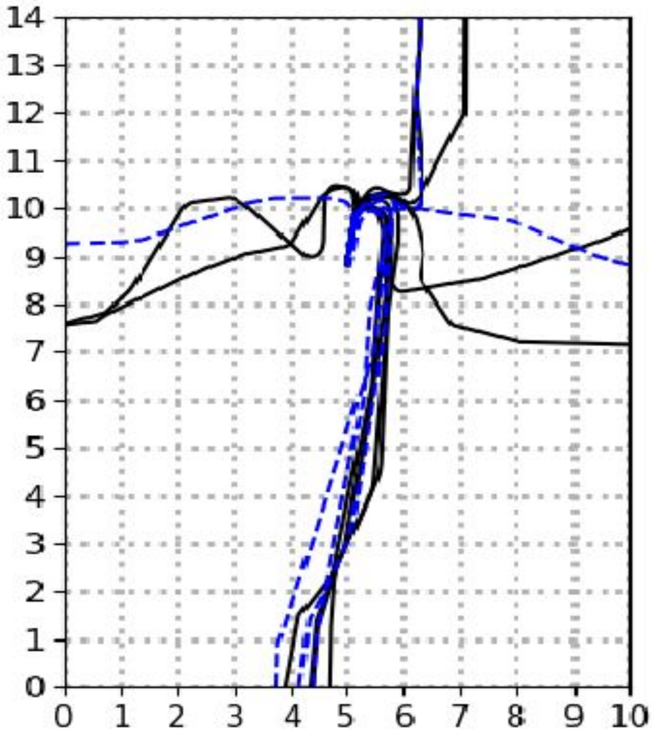


- **Tree 1:** time: 15:00 - 15:30 (10 a/c)
- **Tree 2:** time: 15:30 - 16:00 (7 a/c)
- U = 23 provides consistency between the trees
- Separation: 2 min, ~6 nm
- 17 out of 22 arrivals scheduled
- 5 filtered out, because of:

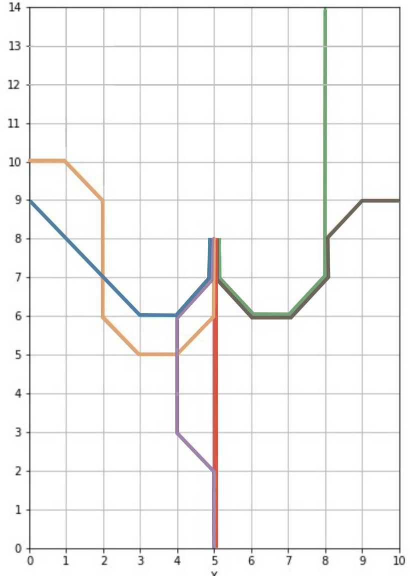
  - Initial violation of separation at entry points
  - Potential overtaking problem
  - In general, about 10-15% are not scheduled

Moderate-traffic scenario: Comparison against the actual trajectories

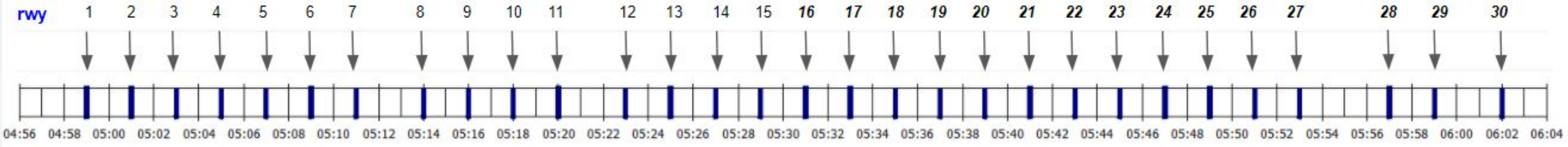




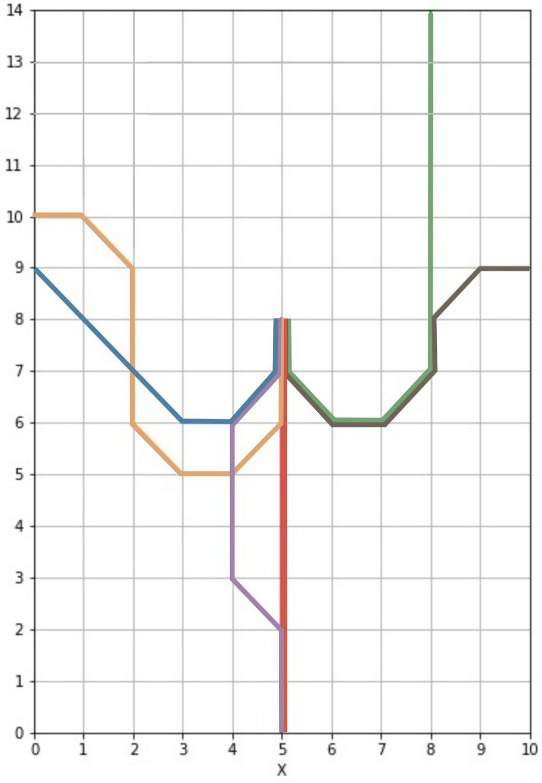
High-traffic scenario: May 16, 2018



- The busiest day in 2018, high traffic
- Separation: 2 min, ~6 nm
- All 30 a/c scheduled (**entry time window ± 5 min**)
- All 30 fly CDO!
- Average deviation from the initial entry time 2.27 min
- Average separation at the runway 2.14 min



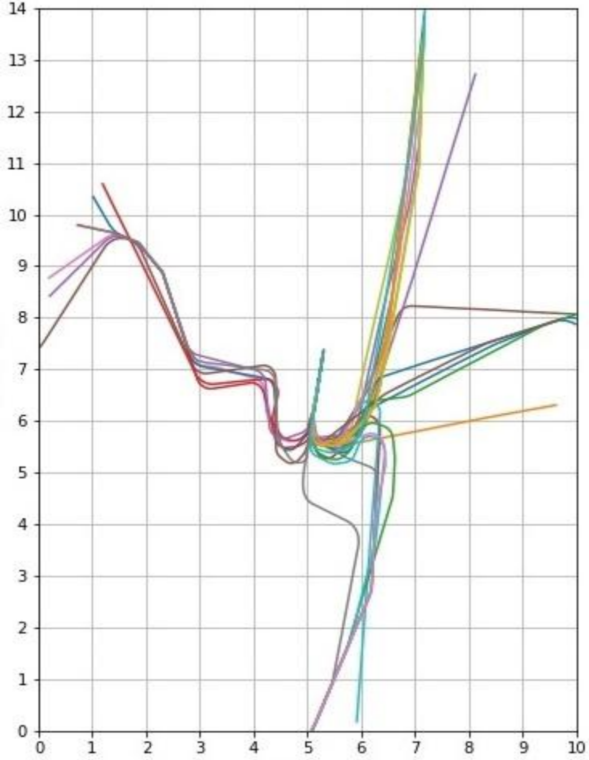
High-traffic scenario: comparison against the actual trajectories



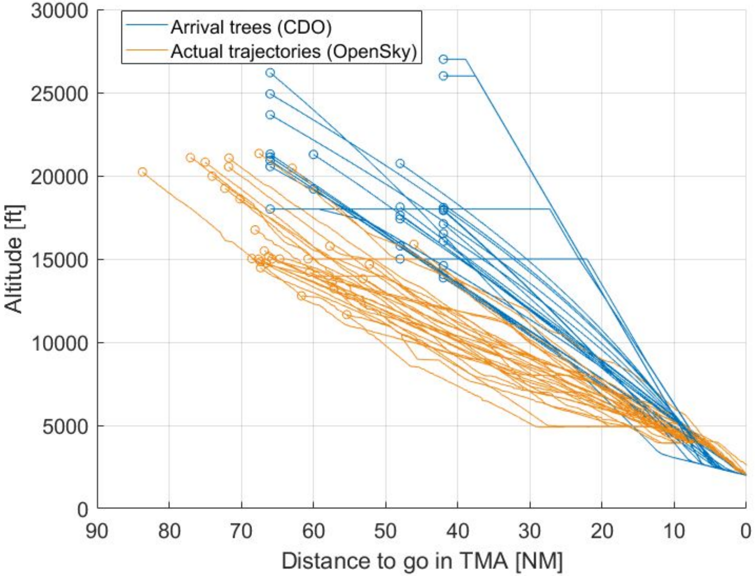
30 arrivals in 1 hour

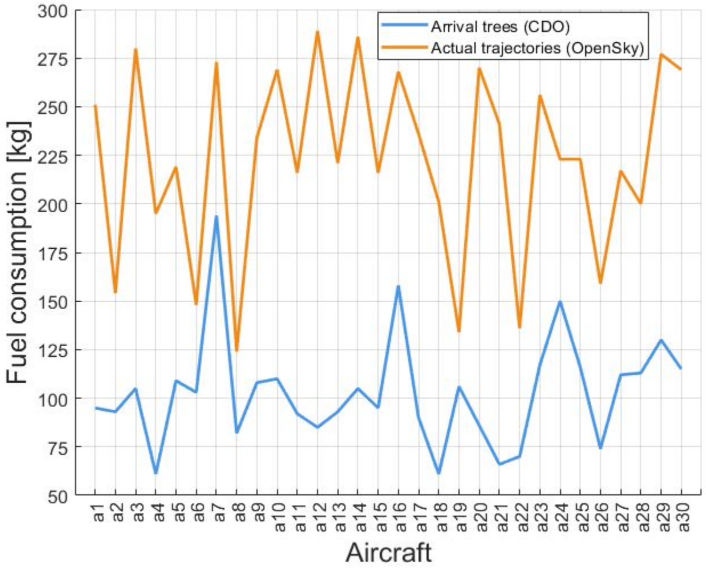
Average time in TMA:

9.5 min vs. **15.1** min



High-traffic scenario: comparison against the actual trajectories





Fuel savings: 3590 kg (~ 54% reduction)

Conclusions

- Flexible optimization framework for dynamic route planning inside TMA
- Automated space and time separation
- Environmentally-friendly speed profiles (CDO) provide significant fuel savings
- May be used for TMA capacity evaluation

Future Work

- Account for uncertainties due to weather
- Consider fleet diversity
- Investigate on noise impact

Future Work

- Account for uncertainties due to weather
- Consider fleet diversity
- Investigate on noise impact

Thank you!

Questions?