Integrated Optimization of Terminal Maneuvering Area and Airport

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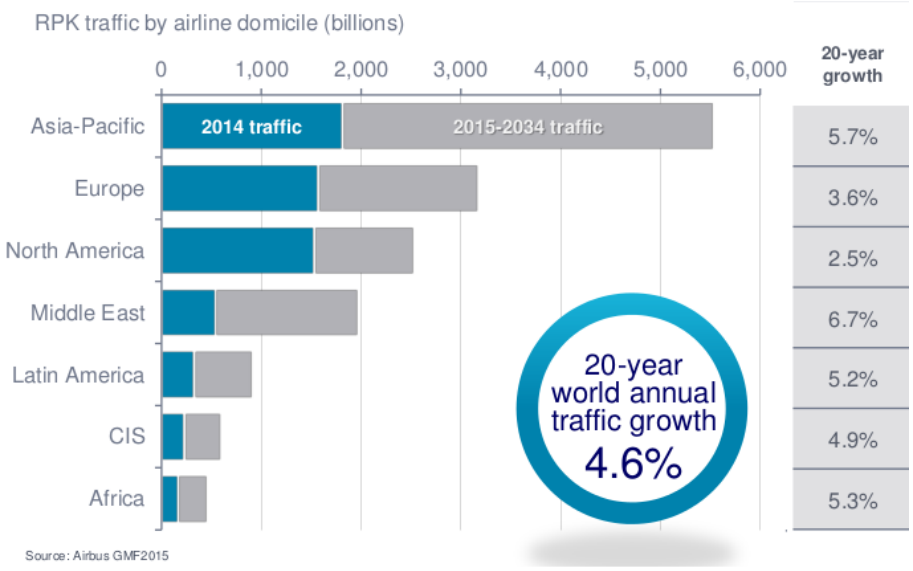
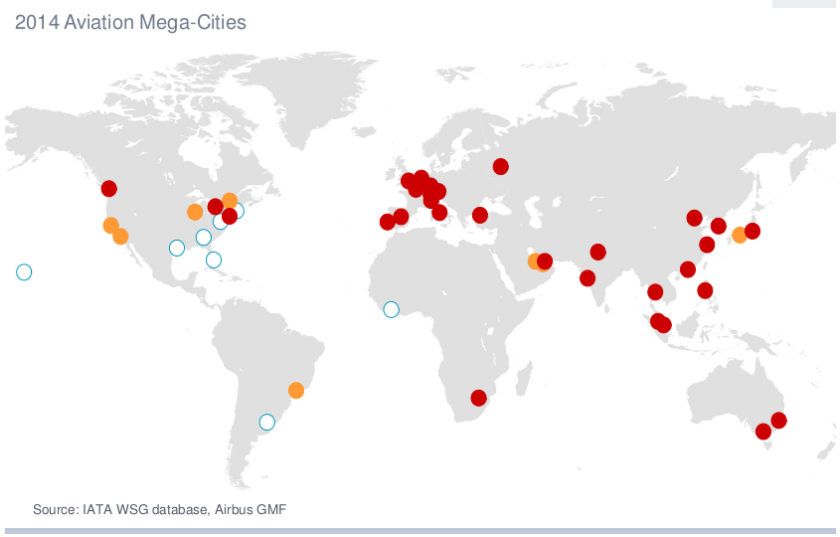
Outline

Outline

Air traffic forecast

- According to Airbus global market forecast 2015-2034, air traffic will double in the next 15 years.



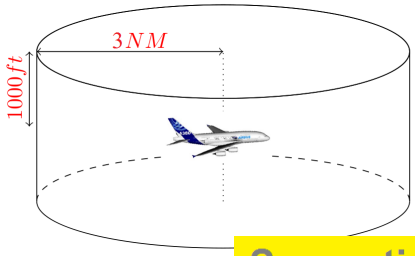


- 39 out of the 47 aviation mega cities are largely congested today.
  - airport infrastructure is adequate
  - airports with potential for congestion
  - airports where conditions make it impossible to meet demand

Background

Airport and surrounding terminal airspaces control is a complex problem.

Runway capacity



Separation

Prohibited area
Restricted area
Dangerous area

Weather

Noise

Sustainable development

Current research

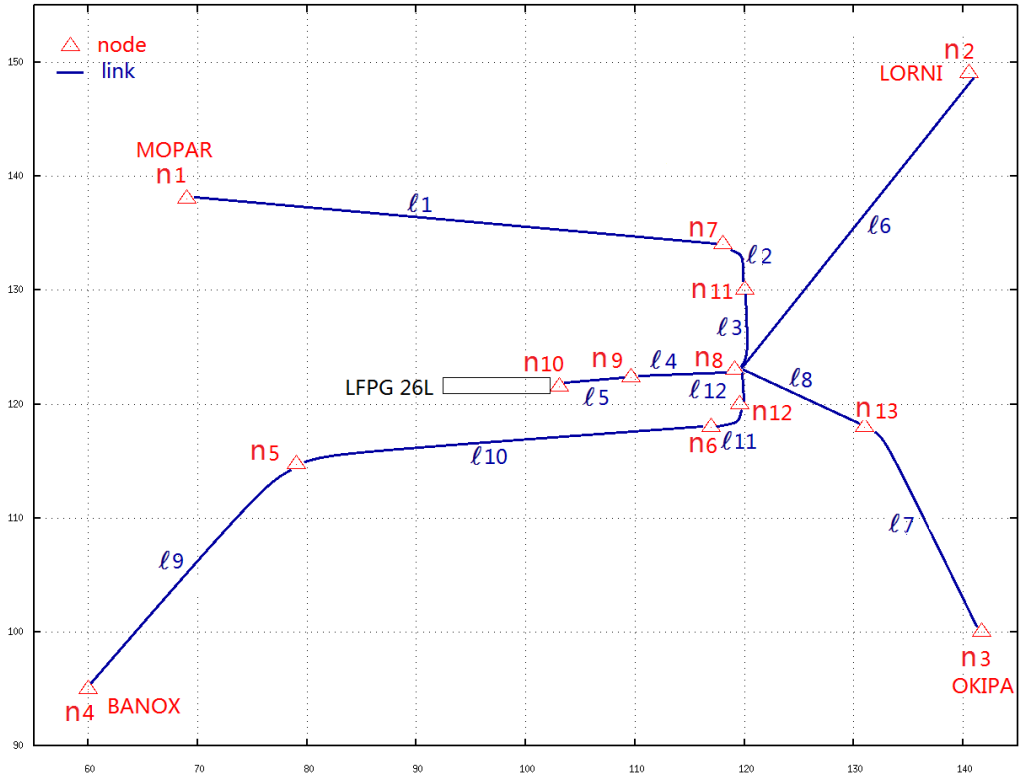
- Arrival Management Problem
  - Landing sequencing
  - Ensure proper separation

- Surface Management Problem
  - Arriving aircraft taxi-in
  - Departing aircraft taxi-out

- Departure Management Problem
  - Take-off times and sequences for departing flights
  - Ensure proper separation

Outline

Given data (1/3)



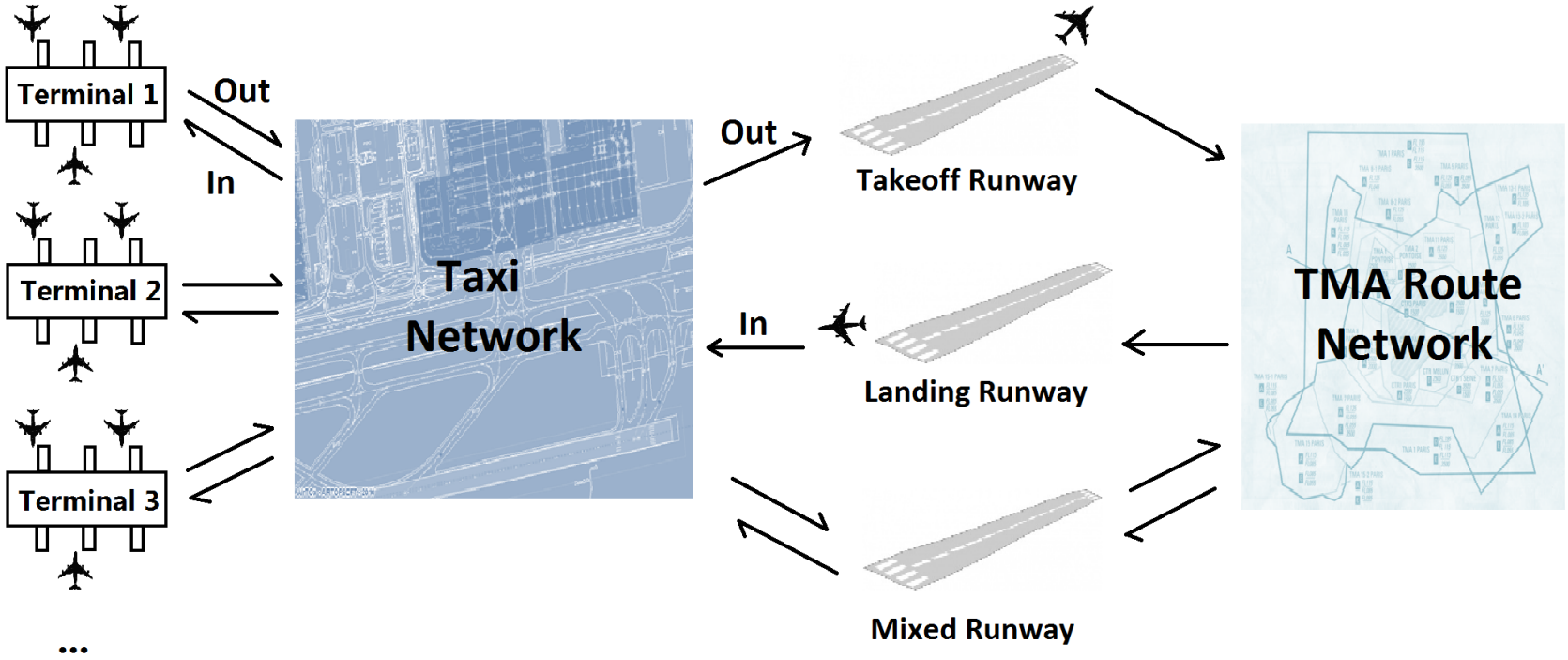
TMA arrival route network

- Node-link graph : $G(\mathscr{N}, \mathscr{L})$, $\mathscr{N}$ node set and $\mathscr{L}$ link set ;
- One route is composed of several links, the first one starts from the entering point and the last link ends at the runway threshold.

Given data (2/3)

Network abstraction

- Overall terminal capacity : number of gates
- Taxi network capacity : threshold of total allowed number of taxi-in and taxi-out aircraft
- Runway type : landing only, departure only, mixed mode



Given data (3/3)

Given a set of flights, $\mathcal{F} = \{1, \ldots, N_f\}$. Each flight can be in one of three operations : $\mathcal{F} = \mathcal{A} \cup \mathcal{D} \cup \mathcal{AD}$, where $\mathcal{A}$ stands for arrival, $\mathcal{D}$ for departure and $\mathcal{AD}$ for arrival-departure.

TABLE : Given information for each operation type

Operation type	$\mathcal{A}$	$\mathcal{D}$	$\mathcal{AD}$
Wake turbulence category	$\surd$	$\surd$	$\surd$
Assigned terminal number	$\surd$	$\surd$	$\surd$
Entering waypoint	$\surd$	$\times$	$\surd$
Initial entry time at TMA	$\surd$	$\times$	$\surd$
Initial speed at TMA	$\surd$	$\times$	$\surd$
Taxi-in duration	$\surd$	$\times$	$\surd$
Earliest off-block time	$\times$	$\surd$	$\surd$
Taxi-out duration	$\times$	$\surd$	$\surd$
Departure runway number	$\times$	$\surd$	$\surd$

Decision variables

- $t_f \in \mathcal{T}_f$ entering time at TMA of flight $f \in \mathcal{A} \bigcup \mathcal{AD}$, where

$$\mathcal{T}_f = \{T_f^0 + j\Delta T \ |\Delta T_{\text{min}}/\Delta T \leqslant j \leqslant \Delta T_{\text{max}}/\Delta T, \ \ j \in \mathbb{Z}\}$$

- $v_f \in \mathcal{V}_f$ entering speed at TMA of flight $f \in \mathcal{A} \bigcup \mathcal{AD}$, where

$$\mathcal{V}_f = \{V_f^{\text{min}} + j\Delta_f^v \mid j \leqslant (V_f^{\text{max}} - V_f^{\text{min}})/\Delta_f^v, j \in \mathbb{N}, \}$$

- $r_f^a \in R_f$ landing runway of flight $f \in \mathcal{A} \bigcup \mathcal{AD}$, where

$$R_f = \text{Set of landing runways}$$

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- $p_f \in \mathcal{P}_f$ pushback delay of flight $f \in \mathcal{D} \bigcup \mathcal{AD}$, where

$$\mathcal{P}_f = \{P_f^0 + j\Delta T \ |0 \leqslant j \leqslant \Delta T_{\text{max}}^p/\Delta T, \ \ j \in \mathbb{N}\}$$

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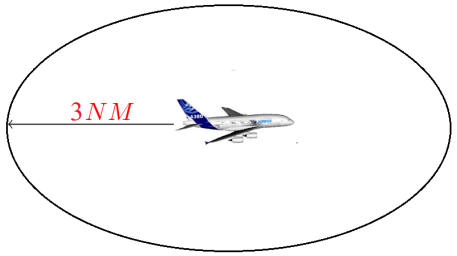
Decision vector :

$$\mathbf{x} = (\mathbf{t}, \mathbf{v}, \mathbf{r}, \mathbf{p})$$

Separation requirements



- Minimum horizontal separation of 3 NM in TMA
- Wake turbulence separation

Category		Leading Aircraft		
		Heavy	Medium	Light
Trailing Aircraft	Heavy	4	3	3
	Medium	5	3	3
	Light	6	5	3

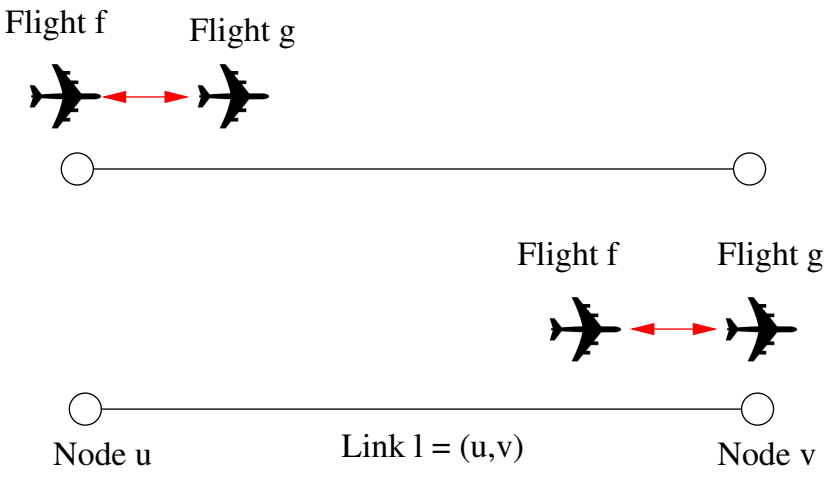
TABLE : Separation minima for two successive aircraft, in NM

- Single-runway separation requirements

Conflicts detection

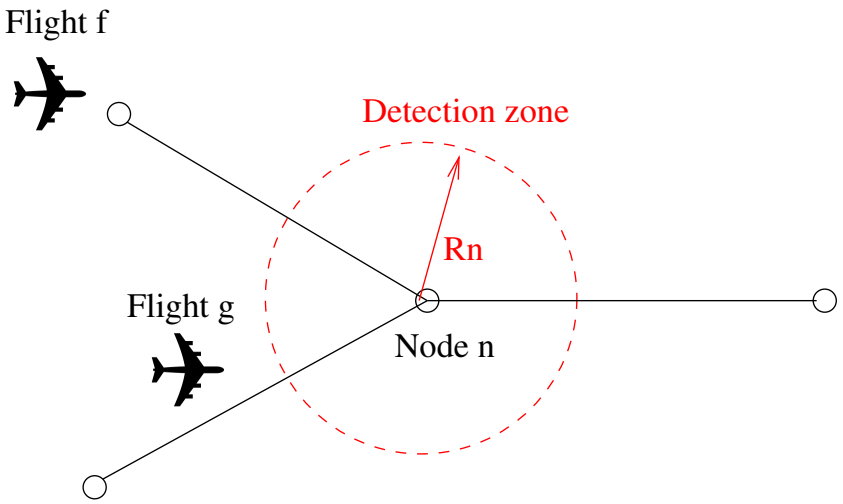
Wake turbulence separation :

- Link conflict



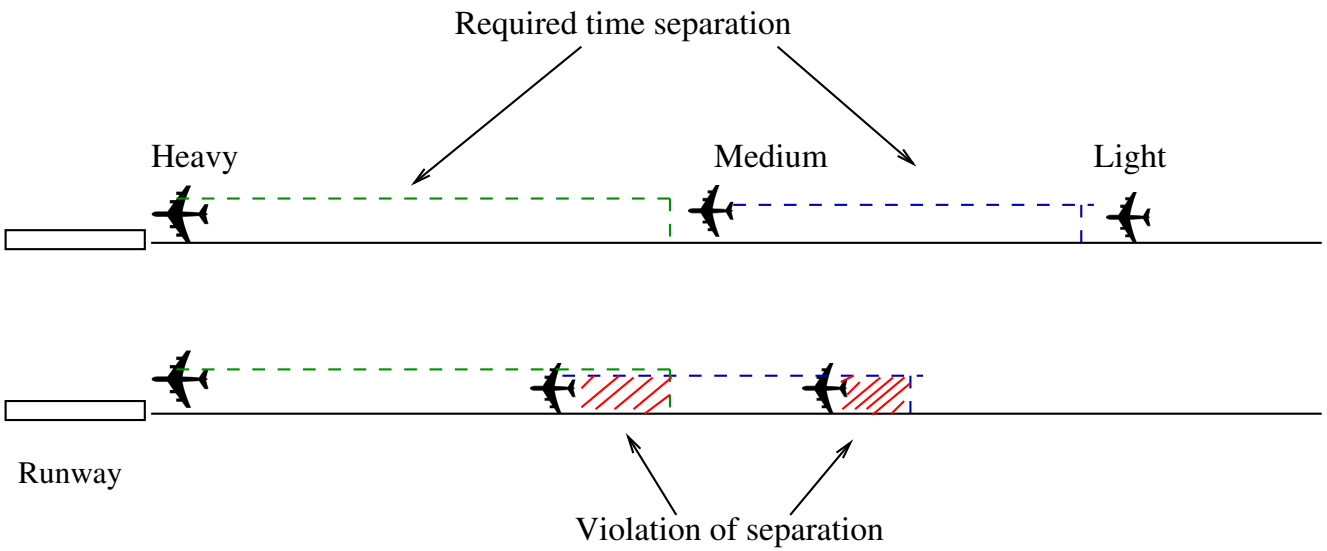
Minimum horizontal separation :

- Node conflict



Runway overload evaluation

We note the accumulated time of separation violation for all pairs of aircraft as an indicator for our runway evaluation.



Landing minimum separation times (in seconds)

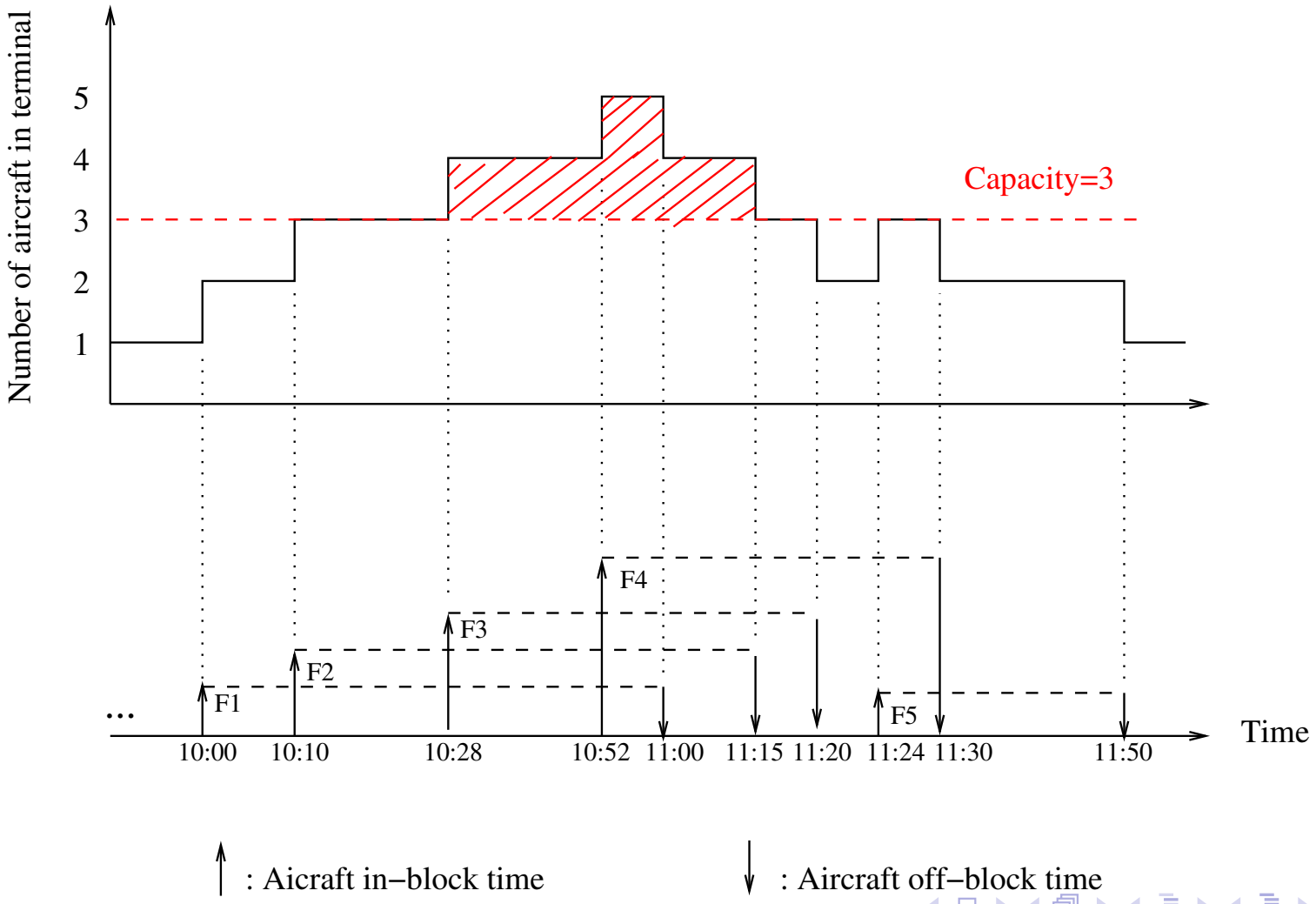
Pred.\Succ.	Heavy	Medium	Light
Heavy	96	157	207
Medium	60	69	123
Light	60	69	82

Take-off minimum separation times (in seconds)

Pred.\Succ.	Heavy	Medium	Light
Heavy	96	111	120
Medium	60	60	60
Light	60	60	60

Terminal and taxi network overload evaluation

We measure the maximum overload number and the total amount of time during which aircraft experience congestions.



Objective function

We minimize

$$\gamma_a A(\mathbf{x}) + \gamma_s S(\mathbf{x})$$

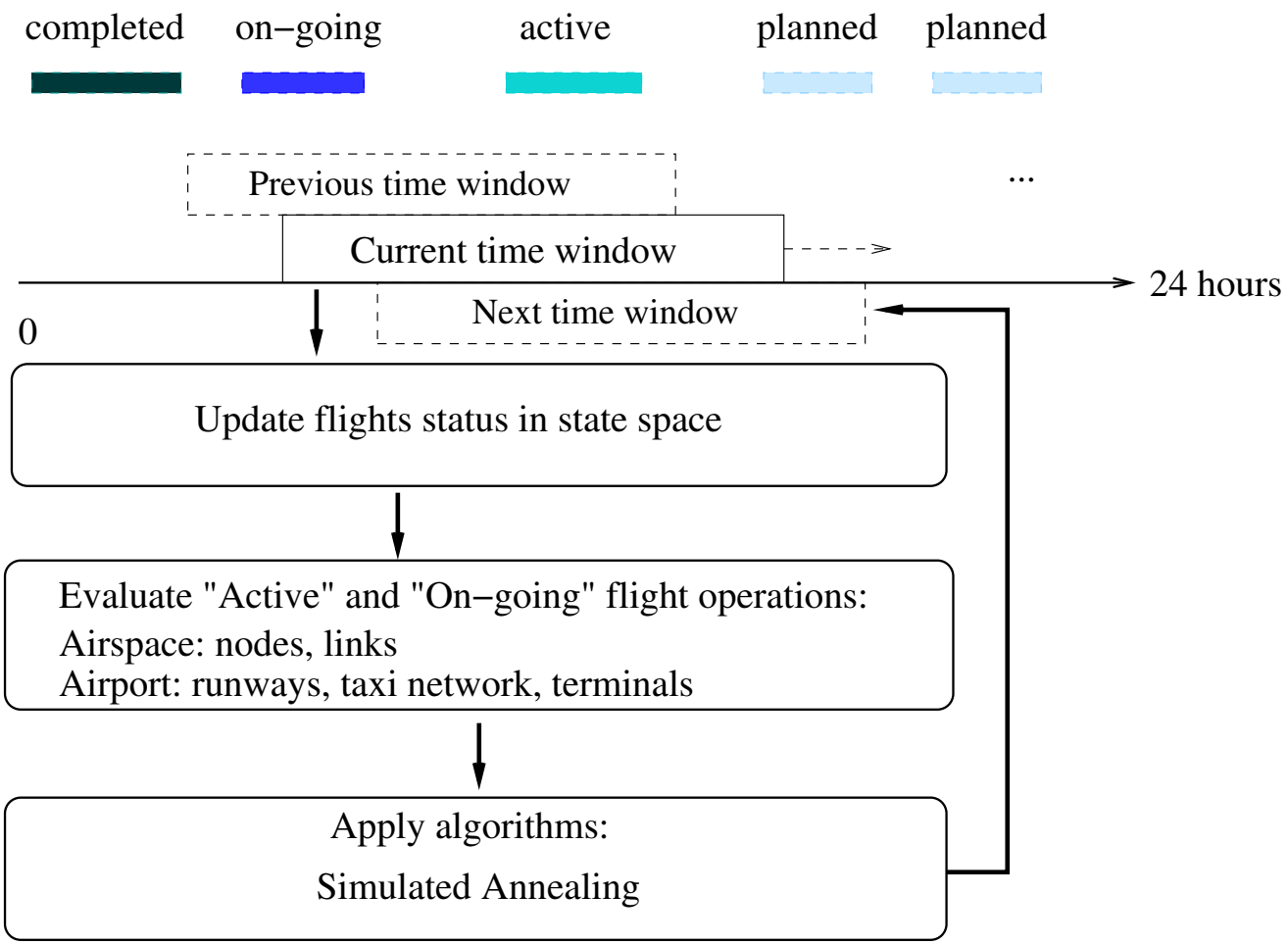
where

- $A(\mathbf{x})$: the total number of conflicts in airspace, including :
  - Node conflicts
  - Link conflicts
- $S(\mathbf{x})$: the airside capacity overload, including :
  - Runway overload
  - Terminal overload
  - Taxi network overload
- Weighting coefficients γ_a, γ_s

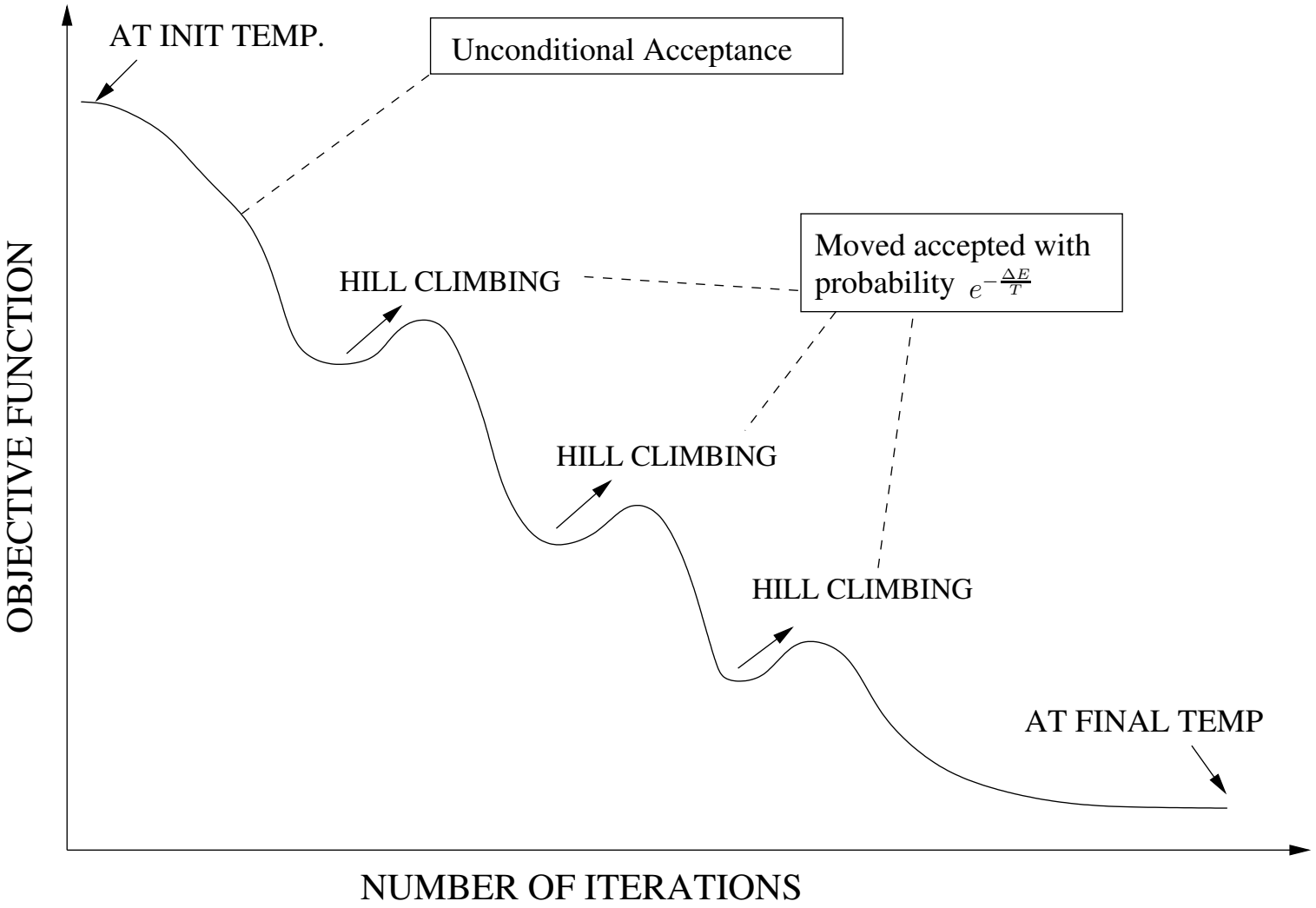
Outline

Solution approaches

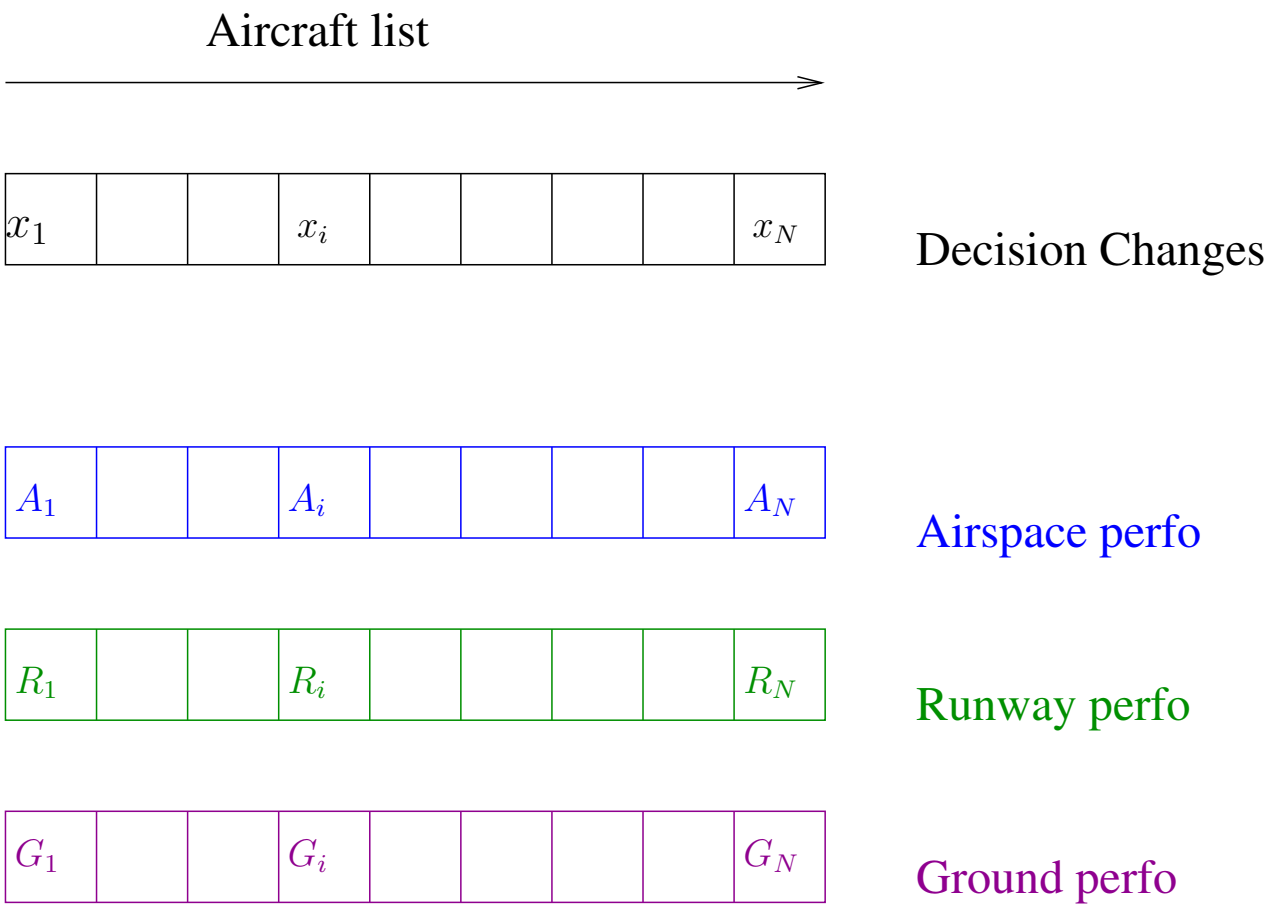
Using time decomposition approach combined with heuristic algorithm.



Simulated annealing

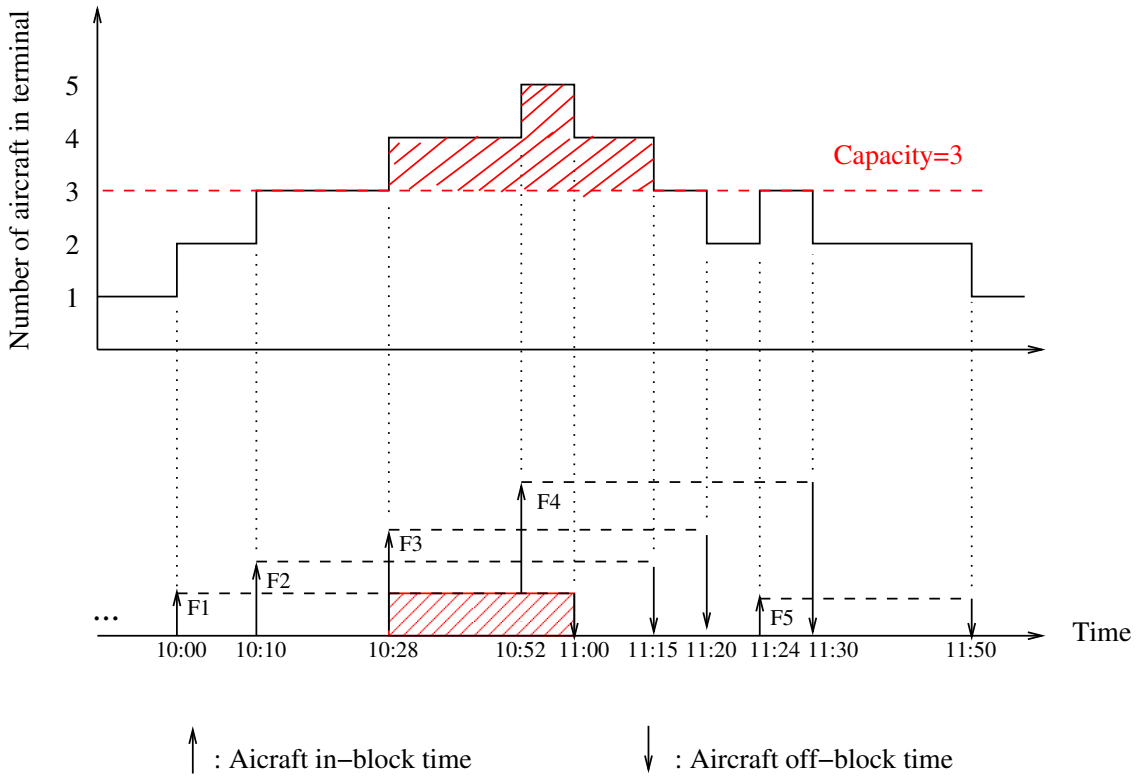


Neighborhood selection (1/3)



Neighborhood selection (2/3)

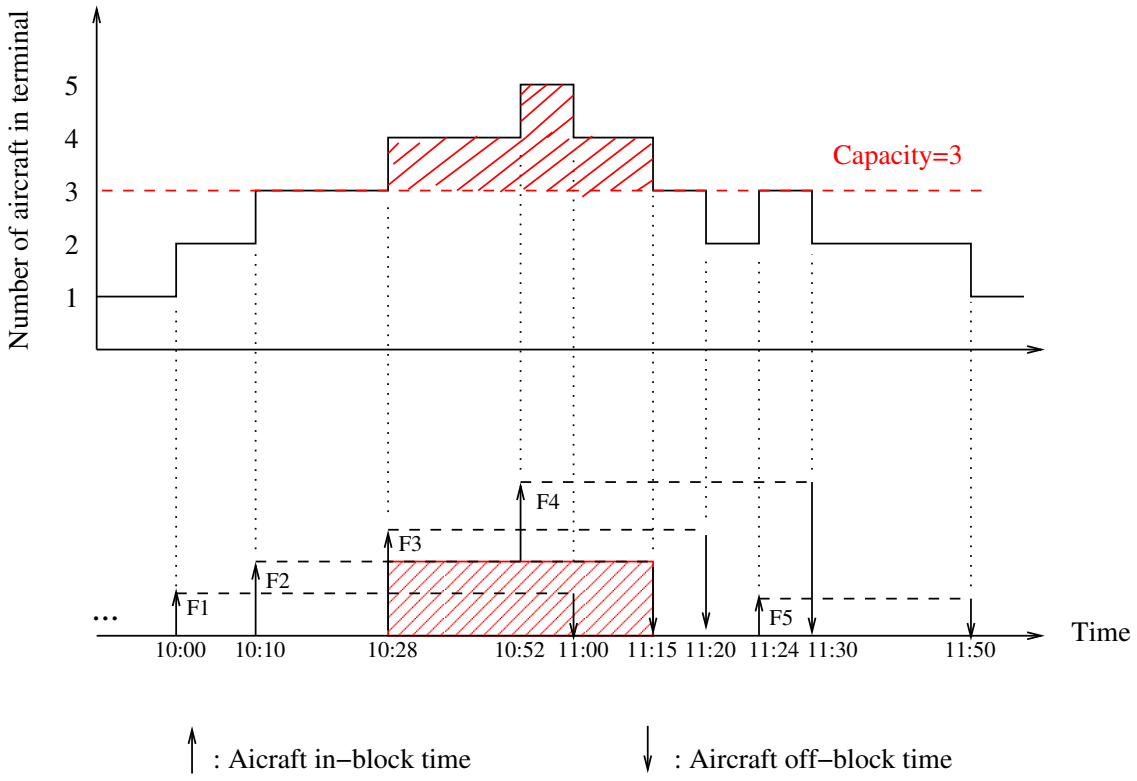
Example (Ground perfo) :



Flight	F1	F2	F3	F4	F5
Ground perfo	32				

Neighborhood selection (2/3)

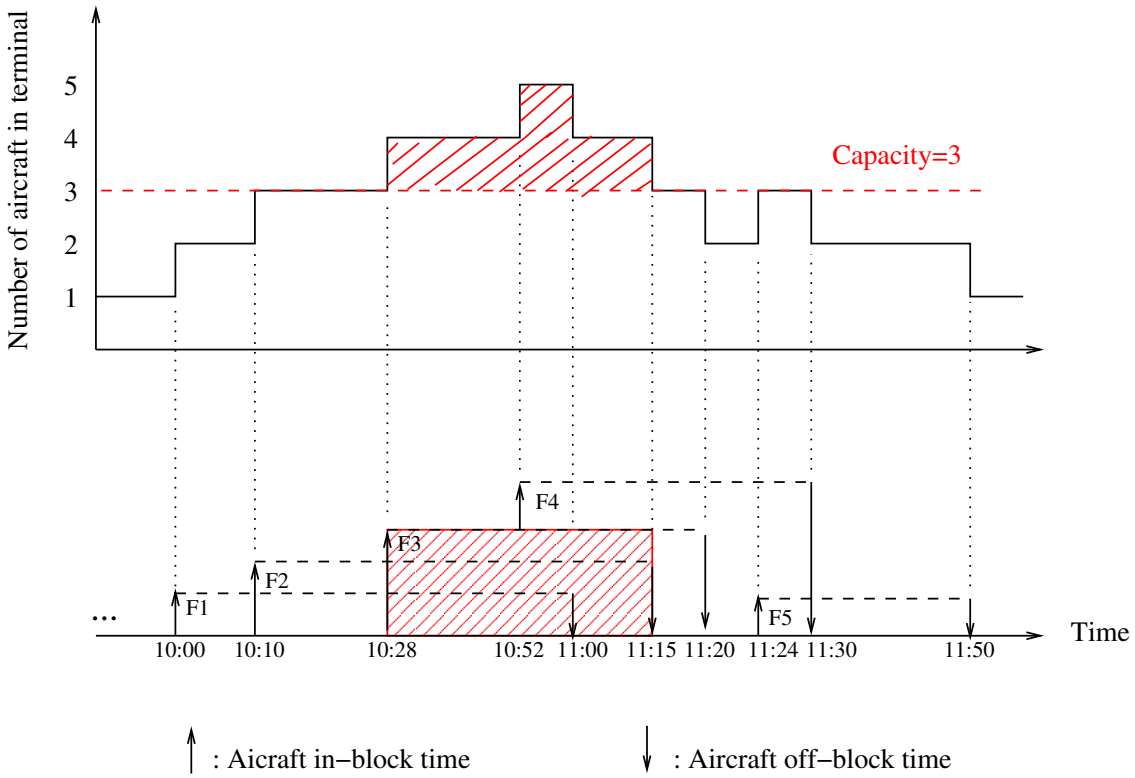
Example (Ground perfo) :



Flight	F1	F2	F3	F4	F5
Ground perfo	32	47			

Neighborhood selection (2/3)

Example (Ground perfo) :



Flight	F1	F2	F3	F4	F5
Ground perfo	32	47	47		

Neighborhood selection (2/3)

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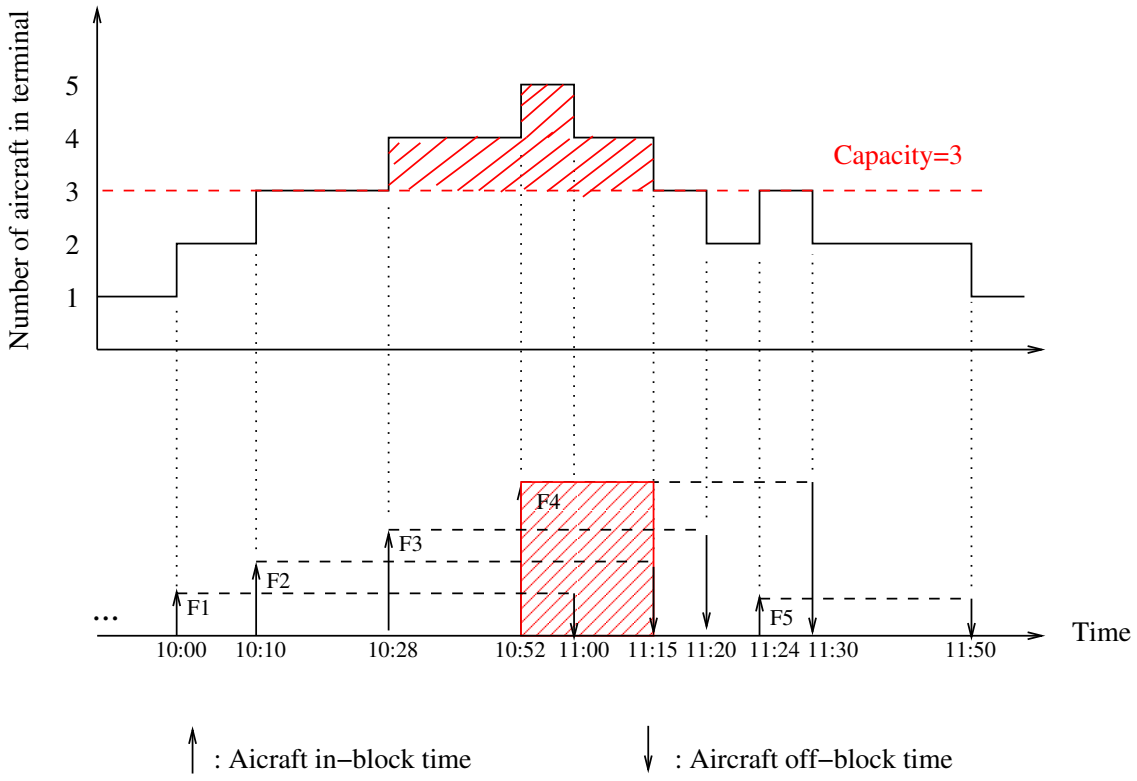
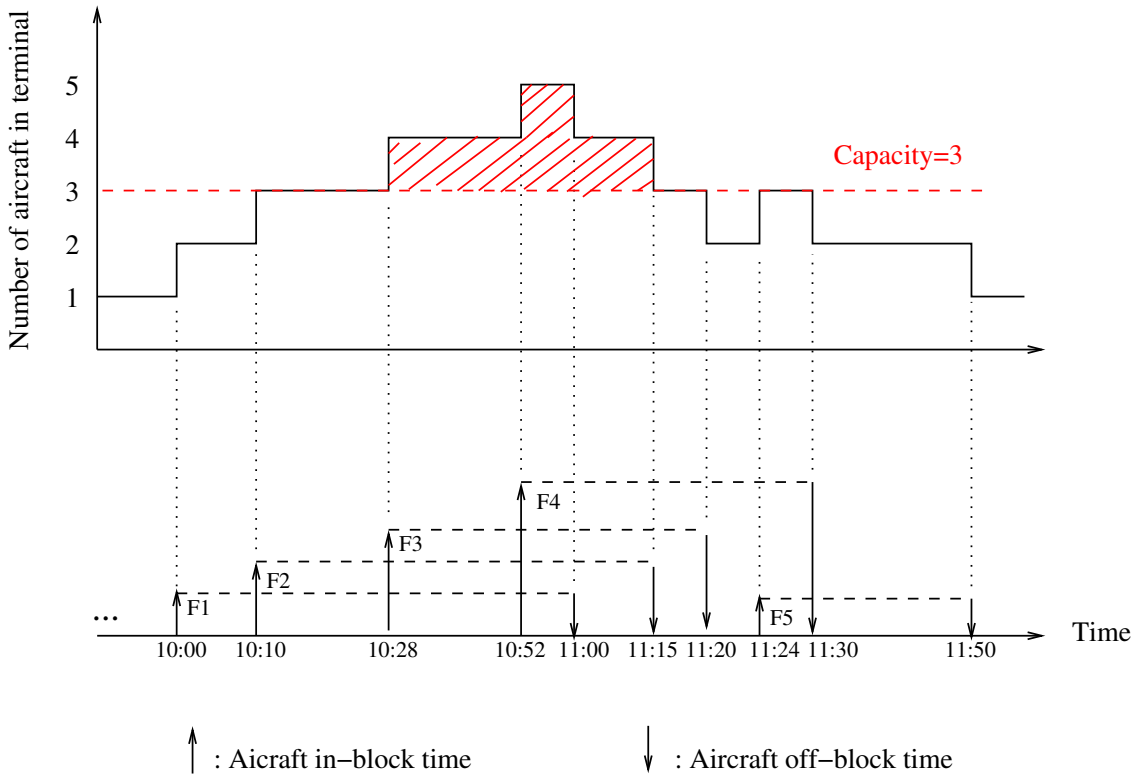


Flight	F1	F2	F3	F4	F5
Ground perfo	32	47	47	23	

Neighborhood selection (2/3)

Example (Ground perfo) :



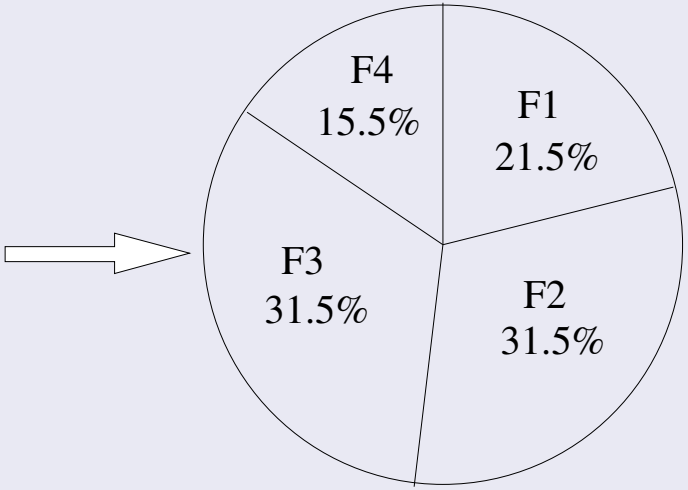
Flight	F1	F2	F3	F4	F5
Ground perfo	32	47	47	23	0

Neighborhood selection (3/3)

Neighborhood

Example :

Flight	F1	F2	F3	F4	F5
Ground perfo	32	47	47	23	0
Percentage	21.5%	31.5%	31.5%	15.4%	0

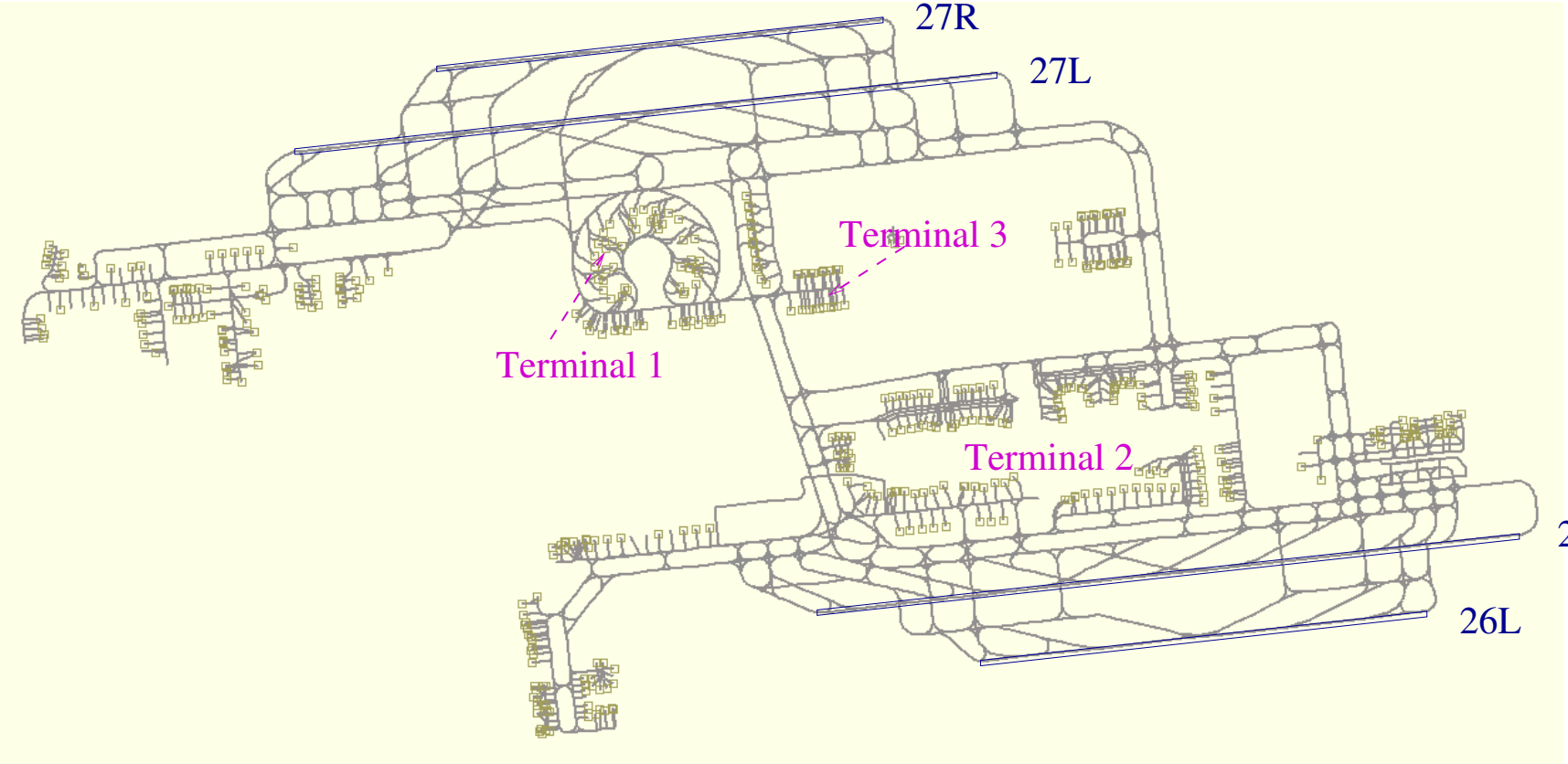


- Roulette wheel selection
- change v_f or t_f if flight $f \in \mathcal{A}$
- change p_f if flight $f \in \mathcal{D}$

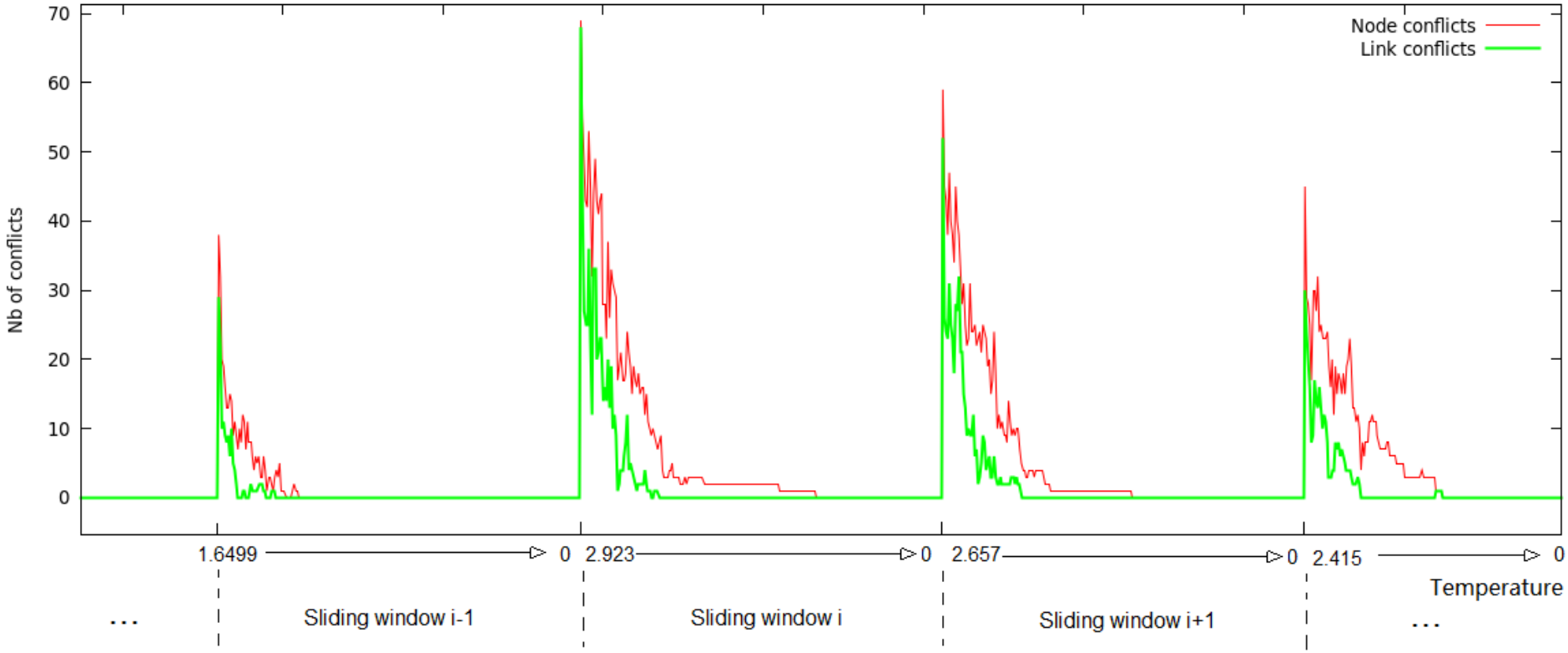
Outline

Case study

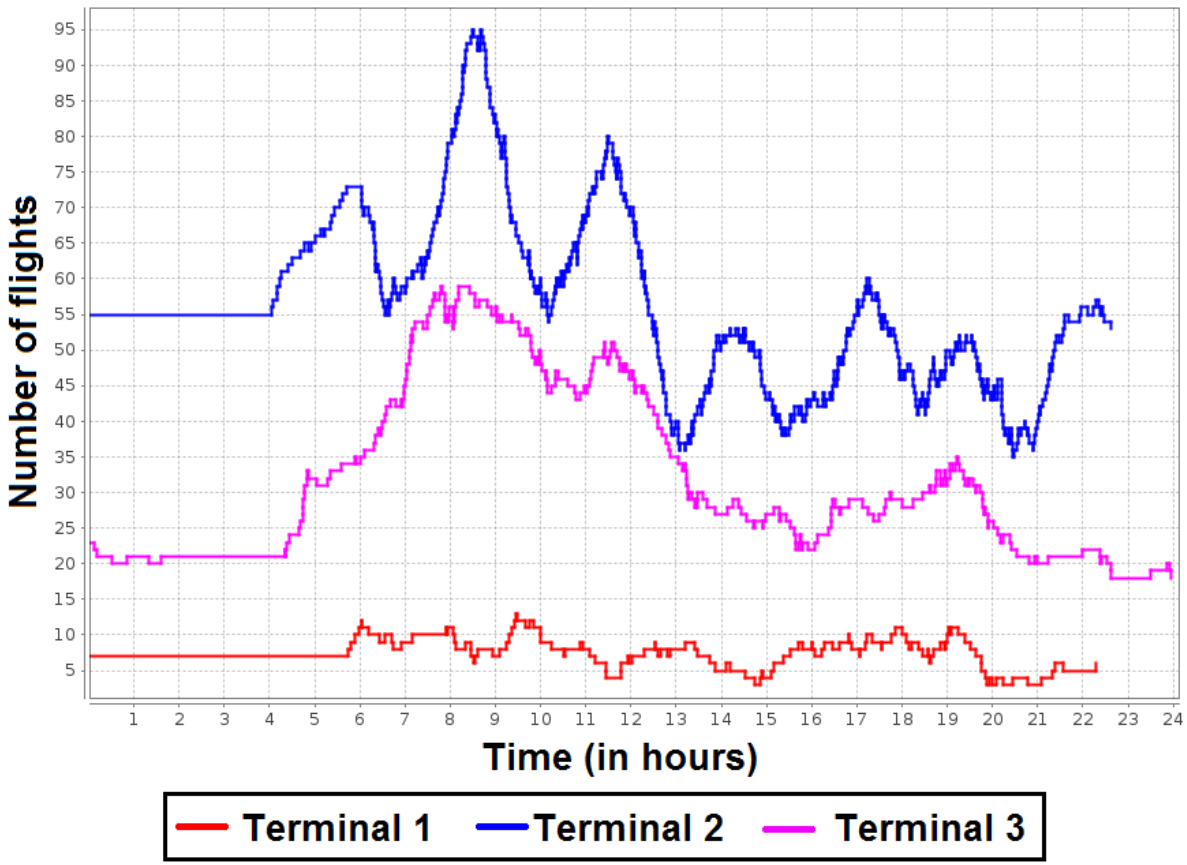
- February 7, 2016 : 562 departures, 554 arrivals.
- Paris CDG airport layout



Conflicts evaluation

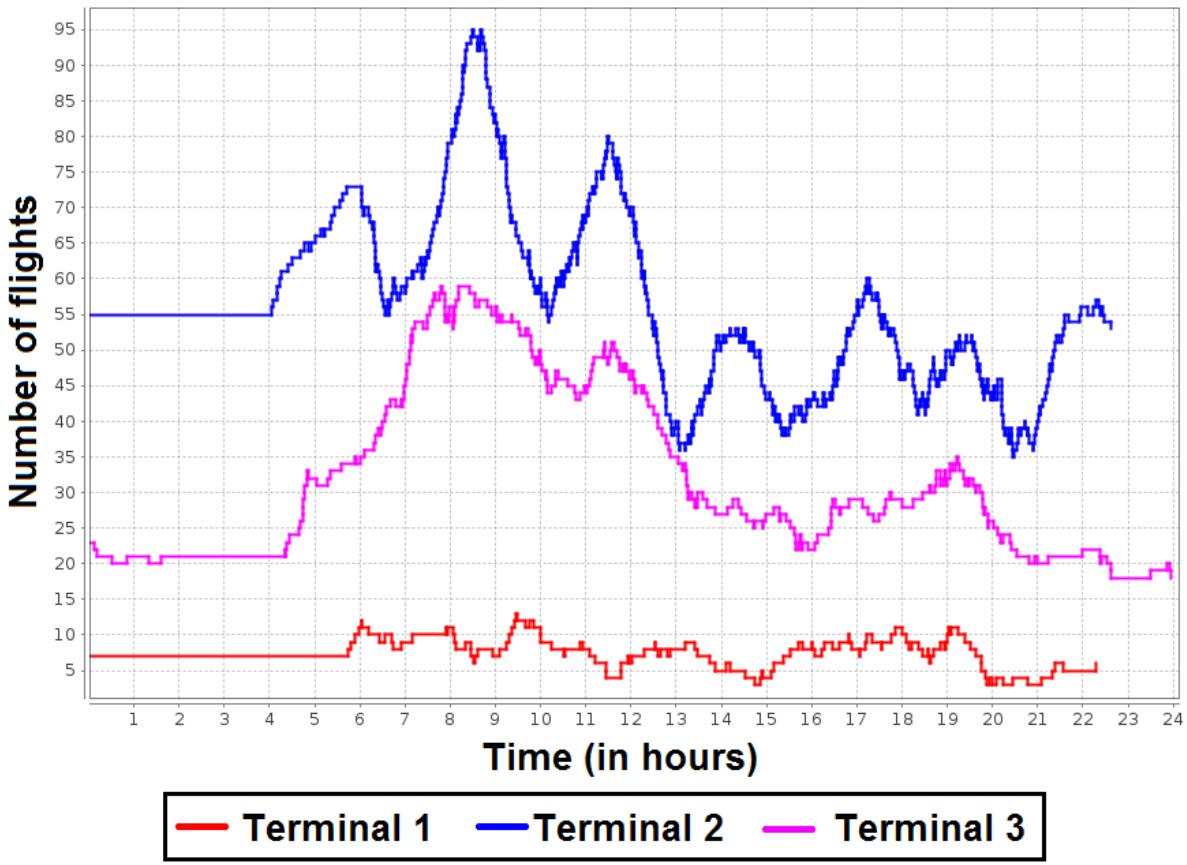


Initial gate occupancy for each terminal



	Terminal 1	Terminal 2	Terminal 3
Max gate occupancy	13	95	59

Initial gate occupancy for each terminal



	Terminal 1	Terminal 2	Terminal 3
Max gate occupancy	13	95	59
Imposed max capacity	10	90	56

Terminal overload evaluation (1/2)

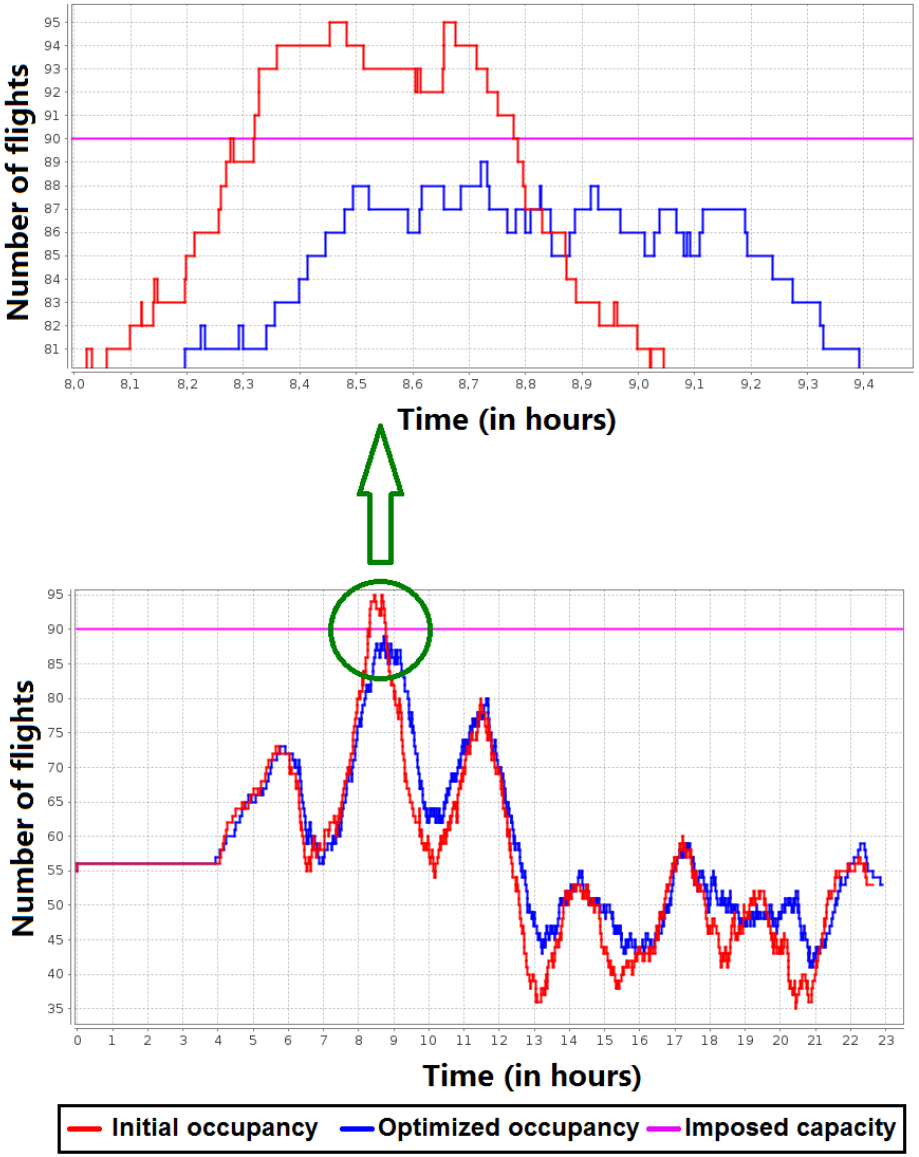
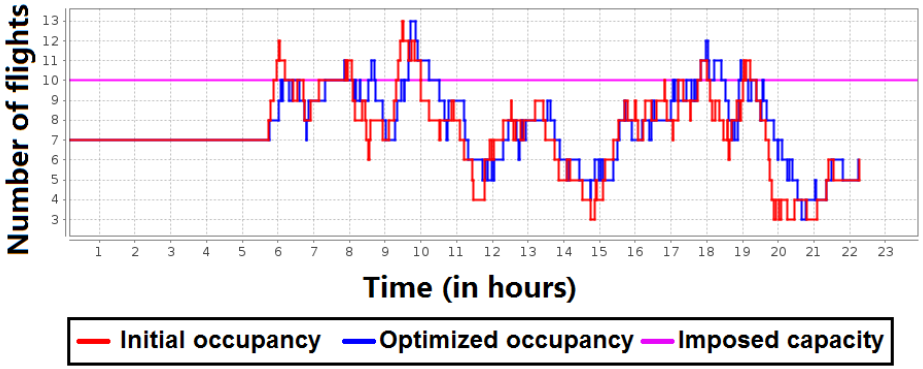
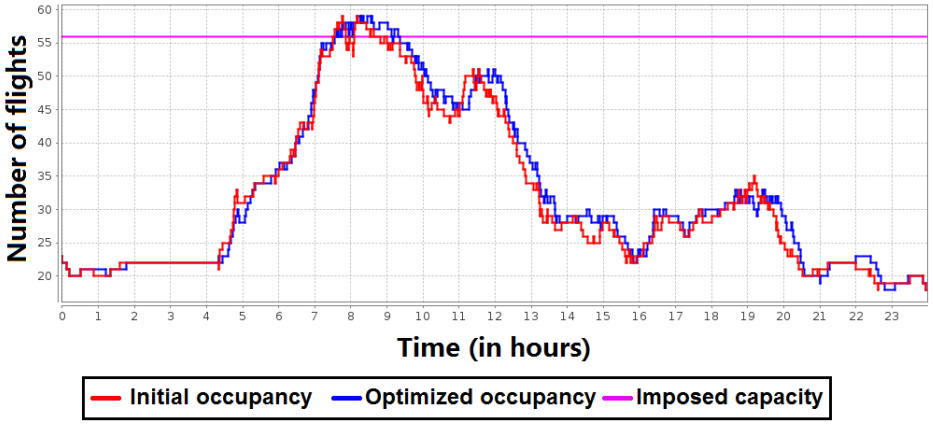


FIGURE : Comparison between initial gate occupancy and optimized one for terminal 2

Terminal overload evaluation (2/2)



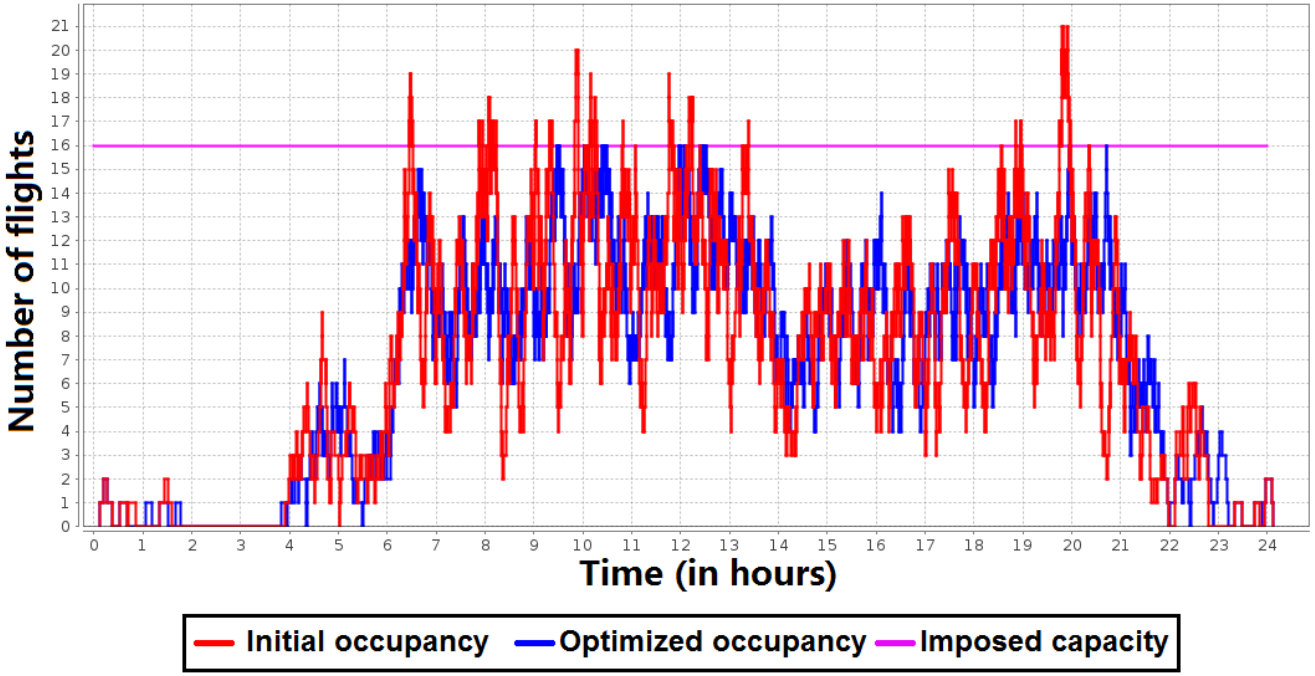
(a) Terminal 1



(b) Terminal 3

FIGURE : Comparison between initial gate occupancy and optimized one for terminal 1 and 3

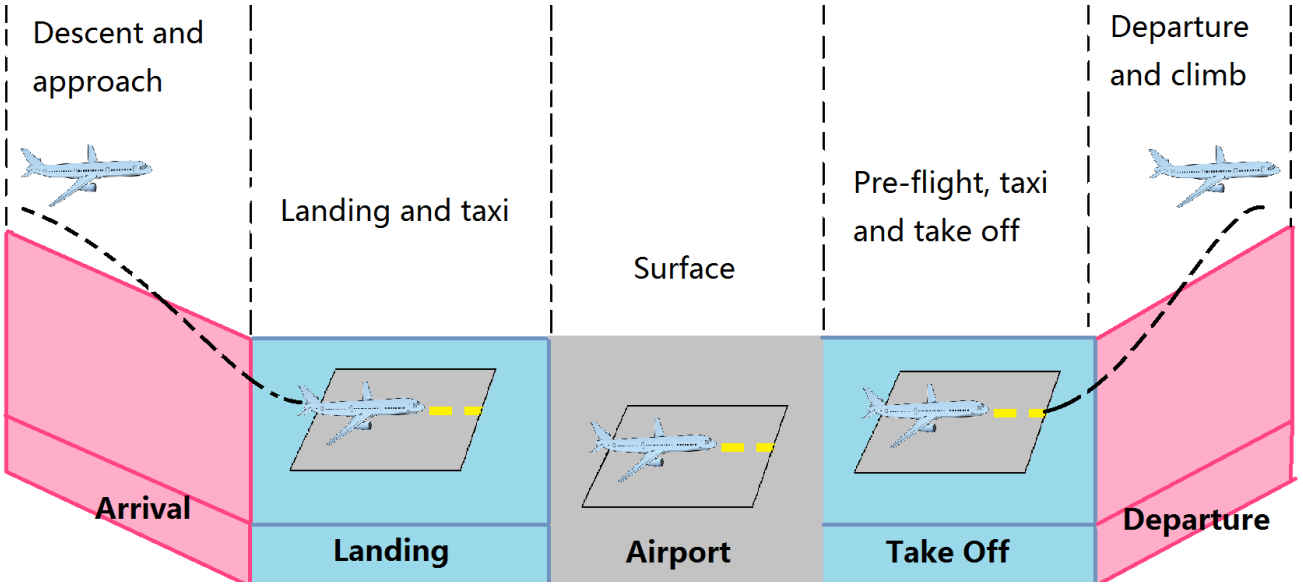
Taxi network overload evaluation



Outline

Conclusions

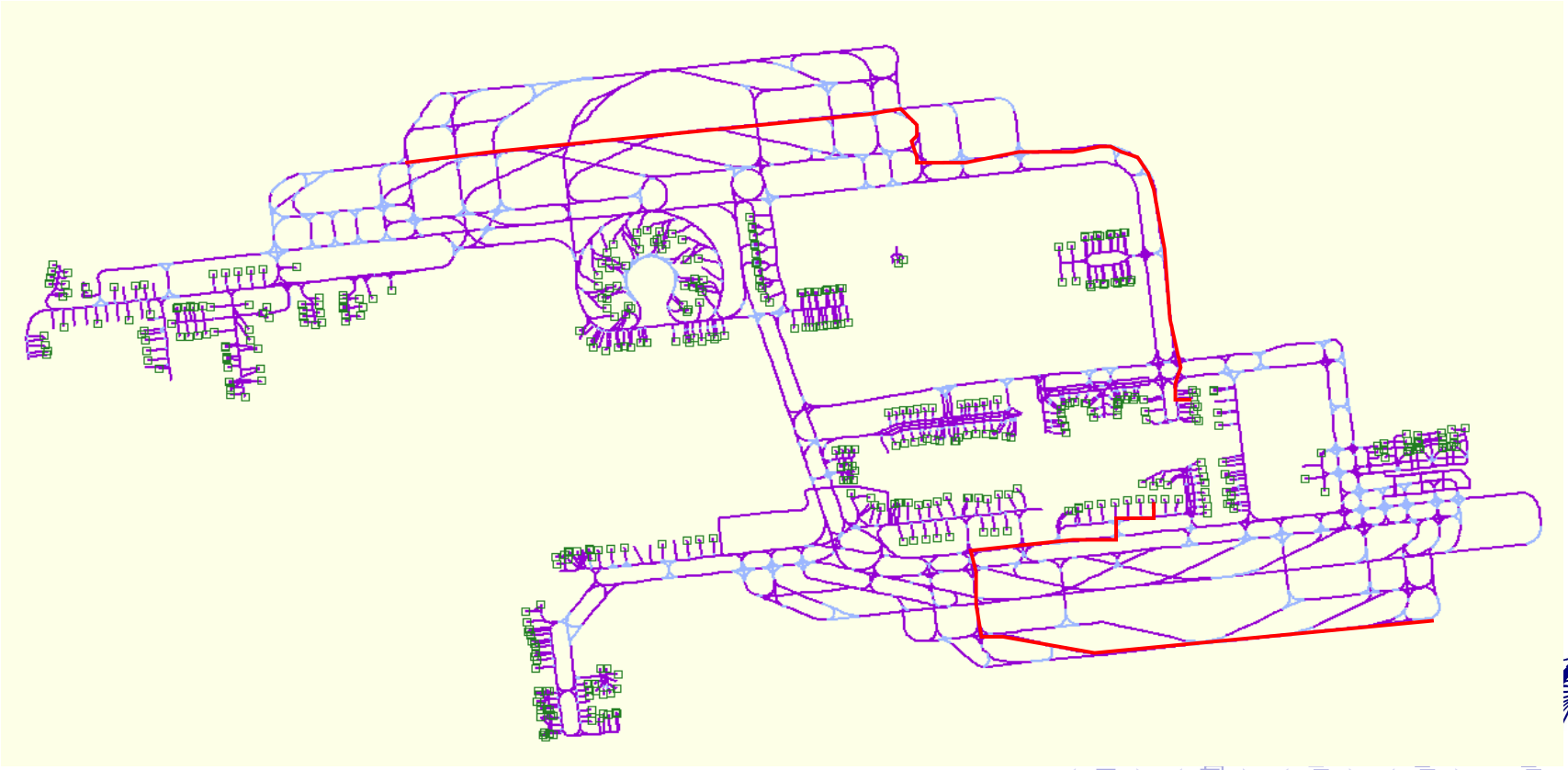
- A TMA route network structure and an abstraction model of airport components
- Time sliding-window approach combined with simulated annealing
- Reaching conflict-free solutions and mitigating the airport overload by time-slot and speed change



Perspectives

Microscopic level optimization

- Taxi In and Taxi Out routes
- Pushback Time update
- This process is repeated by the mean of a sliding time window



Thank you for your attention !