Integrated Traffic Flow Based Optimization of Airport and Terminal Area

9th SESAR Innovation Days

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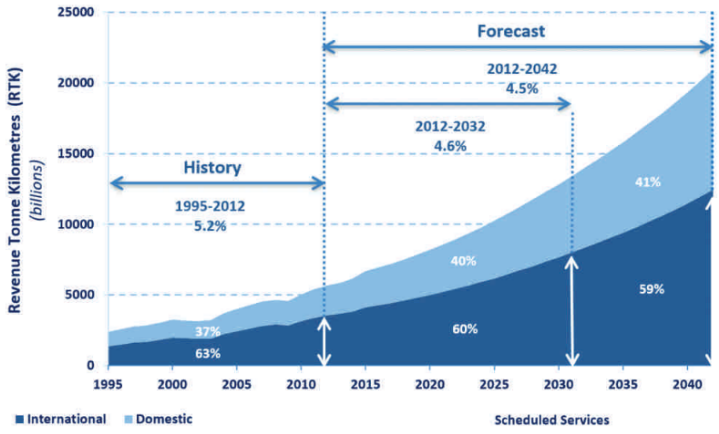
Air traffic evolution

- A continuous growth of the air traffic:
  - Annual growth rate: 4.5%.
  - Will be doubled in the following 15 years.



- Airport and TMA (Terminal Manoeuvring Area) Congestion.
  - Safety issues.
  - Operating costs.

Integrated research

- Arrival Management Problem
  - Landing sequencing
  - Mitigate congestion and conflicts resolution workload

- Surface Management Problem
  - Arriving aircraft taxi-in routes

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

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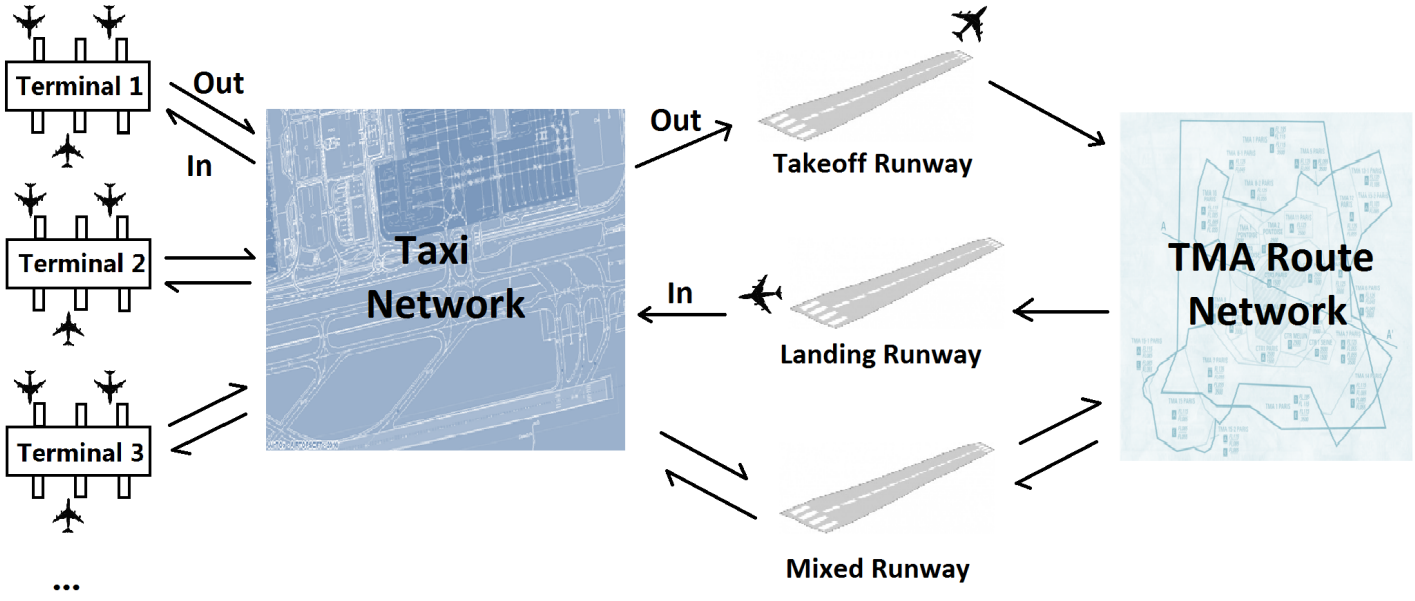
Integrated optimization of TMA and airport

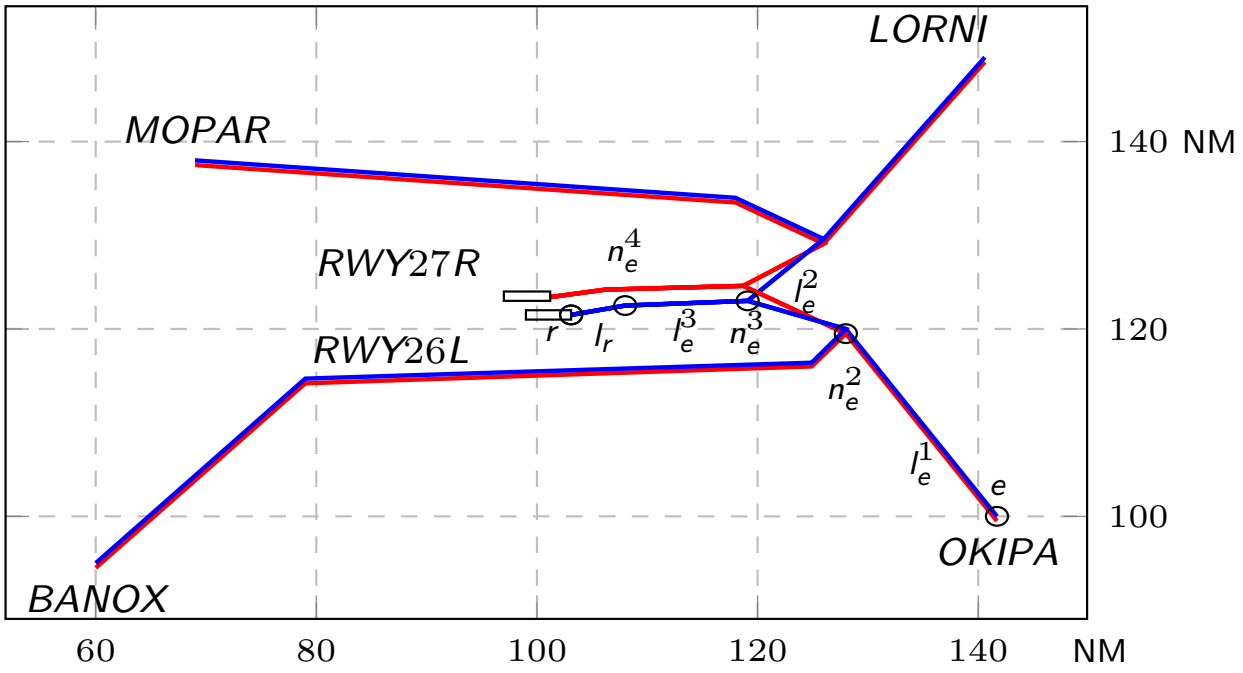
✈ Network abstraction:

- Airside: runways, taxiway network and terminals
- TMA: nodes and links



Network abstraction in TMA

Paris-CDG airport route network for arrivals: Graph($\mathcal{N}$, $\mathcal{L}$).



Given data for optimization

Given a flight $f \in \mathcal{F}$, the flight can be operated with three operations.

Information	Arrival	Departure	Connected flight
Wake turbulence category C_f	✓	✓	✓
Assigned terminal number M_f	✓	✓	✓
Entry node E_f	✓		✓
TMA entry time T_f^o	✓		✓
TMA entry speed V_f^o	✓		✓
Arrival runway R_f^a	✓		✓
Departure runway R_f^d		✓	✓
Scheduled off-block time T_f^d		✓	✓
Turn around time t_f^{ad}			✓

Decision Variables

- TMA entry time t_f :

$$t_f = T_f^o + j\Delta T, \quad j \in [\Delta T_{min}/\Delta T, \Delta T_{max}/\Delta T], \quad j \in \mathbb{Z}$$

- TMA entry speed v_f :

$$v_f = V_f^{min} + j\Delta_f^v, \quad j \in [0, (V_f^{max} - V_f^{min})/\Delta_f^v], \quad j \in \mathbb{N}$$

- Arrival runway r_f^a.

- Pushback delay p_f :

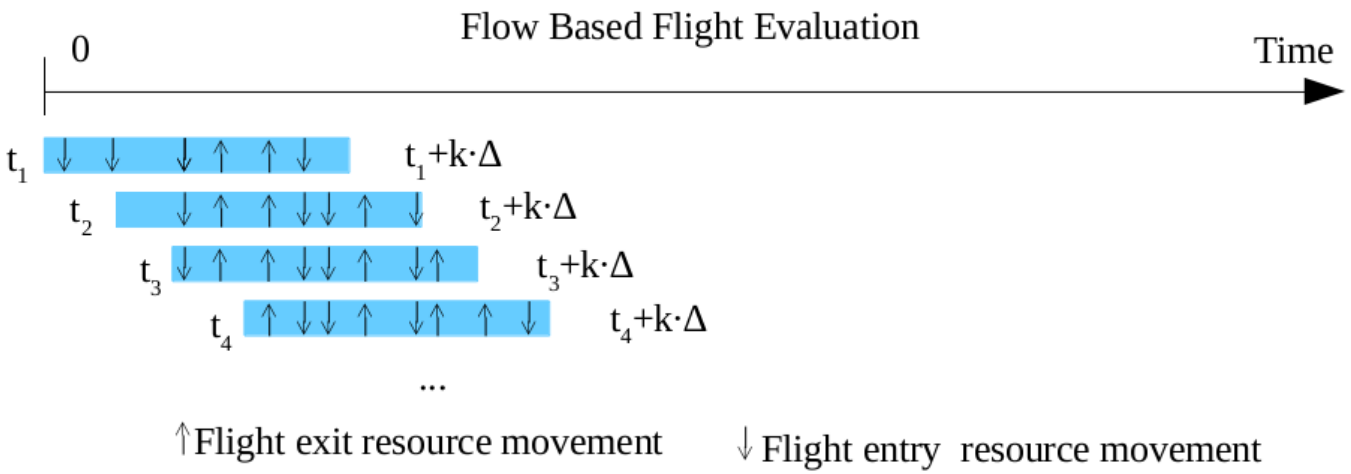
$$p_f = \{P_f^o + j\Delta T\}, \quad j \in [0, \Delta T_{max}^p/\Delta T], \quad j \in \mathbb{N}$$

$$\mathbf{x_f} = (\mathbf{t_f}, \mathbf{v_f}, \mathbf{r_f^a}, \mathbf{p_f})$$

Traffic flow-based model

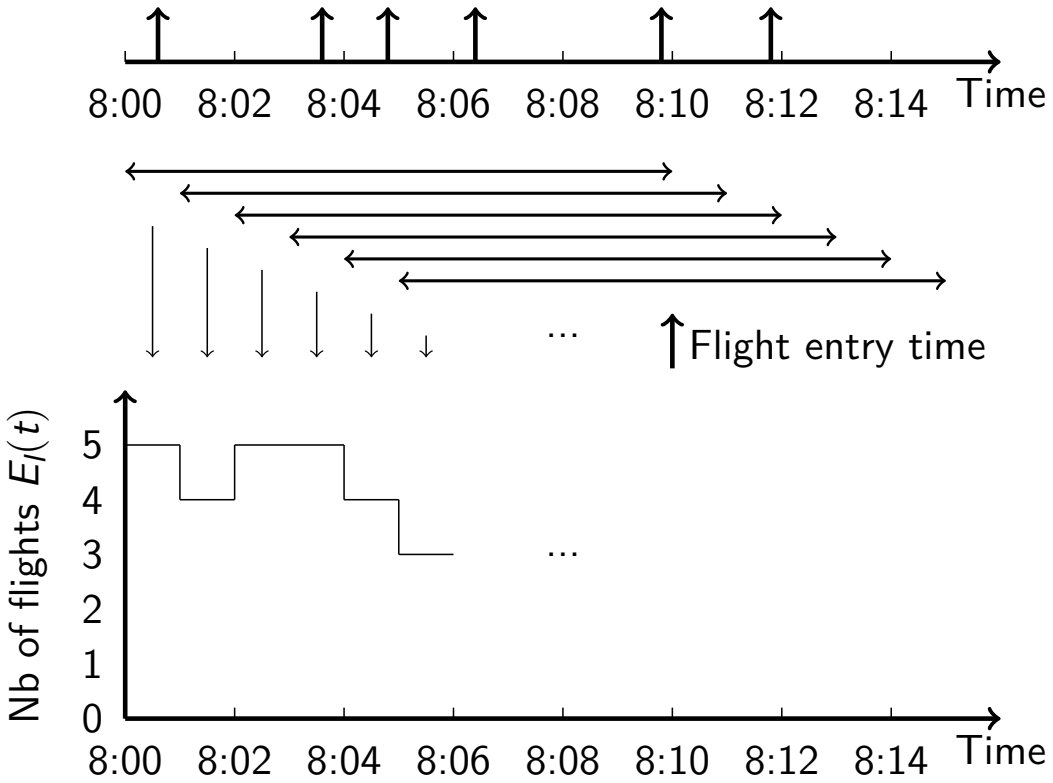
We measure the evaluation values distribution of each resource.
Evaluation parameters:

- Time step/unit: Δ (1 min).
- Evaluation time parameter: k.
- Evaluation time interval: $L = k \cdot \Delta$.
- Evaluation start time t, $t_i = t_{i-1} + \Delta$.



Link evaluation and runway evaluation

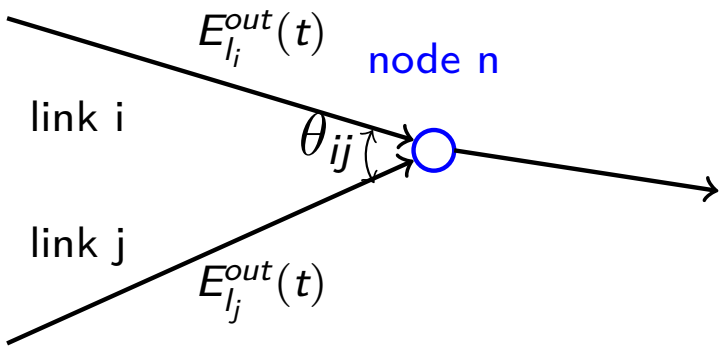
We evaluate the number of flights that enters a link/runway during evaluation time interval t to $t + L$.



- k=10.
- L =10 mins.

Node evaluation

We estimate the conflicts resolution workload.



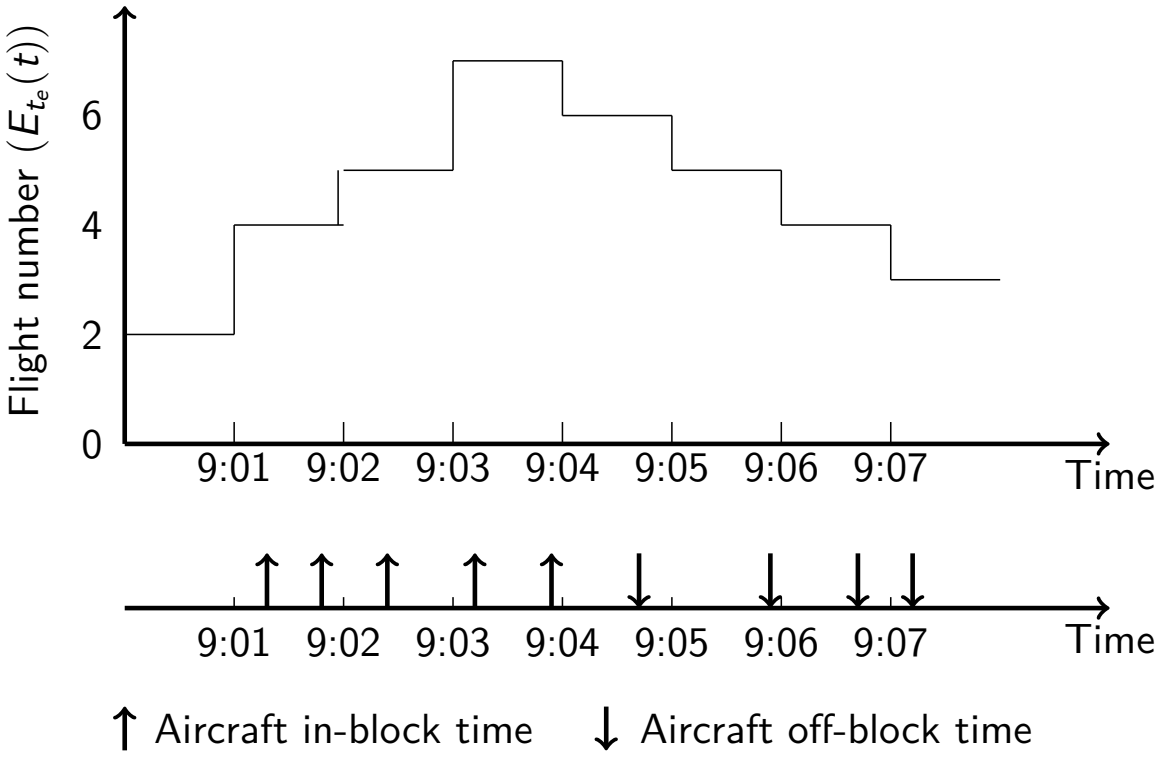
- N_s: standard separation requirement of flights.
- $E_l^{out}(t)$: number of flights that exits link l during t to $t+L$.

$$E_n(t) = \frac{2N_s\sqrt{v_{l_i}^2 - 2v_{l_i}v_{l_j}\cos\theta_{ij} + v_{l_j}^2}}{v_{l_i}v_{l_j}\sin\theta_{ij}} \cdot E_{l_i}^{out}(t)E_{l_j}^{out}(t) \quad n \in \mathcal{N}$$

Airside evaluation

We evaluate the number of flights at each time interval.

- k=1.
- L= 1min.



Capacities constraints

- Link capacity:

$$C_l = \frac{M \cdot v_l}{K}$$

- M: link separation 1 flight/ 5NM.
- K= 1 hour/ L: time scale.
- v_l: average speed on link l.

- Node capacity: C_n= 6 conflicts resolutions / hour.
- Airside capacity.

Landing Runway	Departure Runway	Terminal 1	Terminal 2	Terminal 3	Taxiway
30/h	40/h	20	130	25	19

Objective function

- First metric: average congestion during time horizon T.
- Second metric: the maximum overload during time horizon T.

$$G(\mathbf{x}) = \sum_{s \in \mathcal{S}} \gamma_s \left[\frac{1}{T} \sum_{t \in T} [max(E_s(t) - C_s, 0) \cdot \Delta] \right] + \sum_{s \in \mathcal{S}} \gamma_s \left[\max_{t \in T} [max(E_s(t) - C_s, 0)] \right]$$

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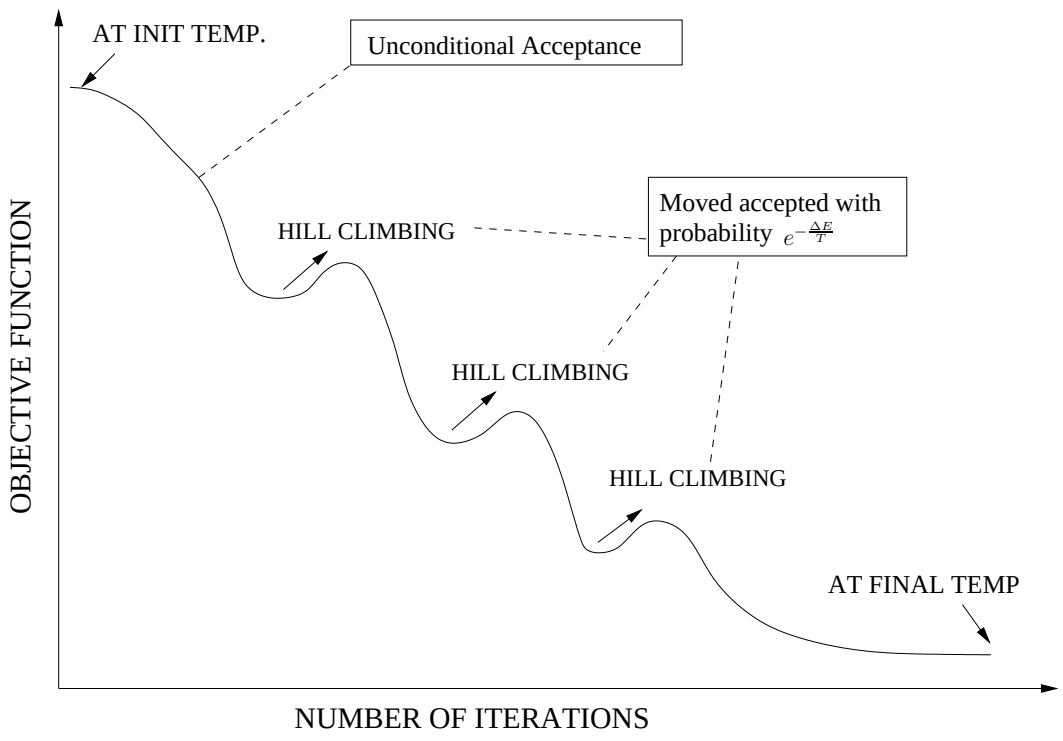
Simulated annealing



- Temperature
- Objective function
- Neighborhood
- Stopping criterion

Neighborhood solution selection

	Airspace performance	Ground performance	Total performance	
f_1	a_1	g_1	m_1	
f_2	a_2	g_2	m_2	$p_a^f = a_f / m_f$
...	...	...	...	$p_g^f = g_f / m_f$
f_N	a_N	g_N	m_N	

- We choose a random number $n \in [0, 1]$ for the decision variable choosing:

$f \in \mathcal{A}$		$f \in \mathcal{AD}$		$f \in \mathcal{D}$
$n < p_a^f$	$n > p_a^f$	$n < p_a^f$	$n > p_a^f$	–
$t_f,\ v_f$	$t_f,\ v_f\ r_f^a$	$t_f,\ v_f$	$t_f,\ v_f, r_f^a, p_f$	p_f

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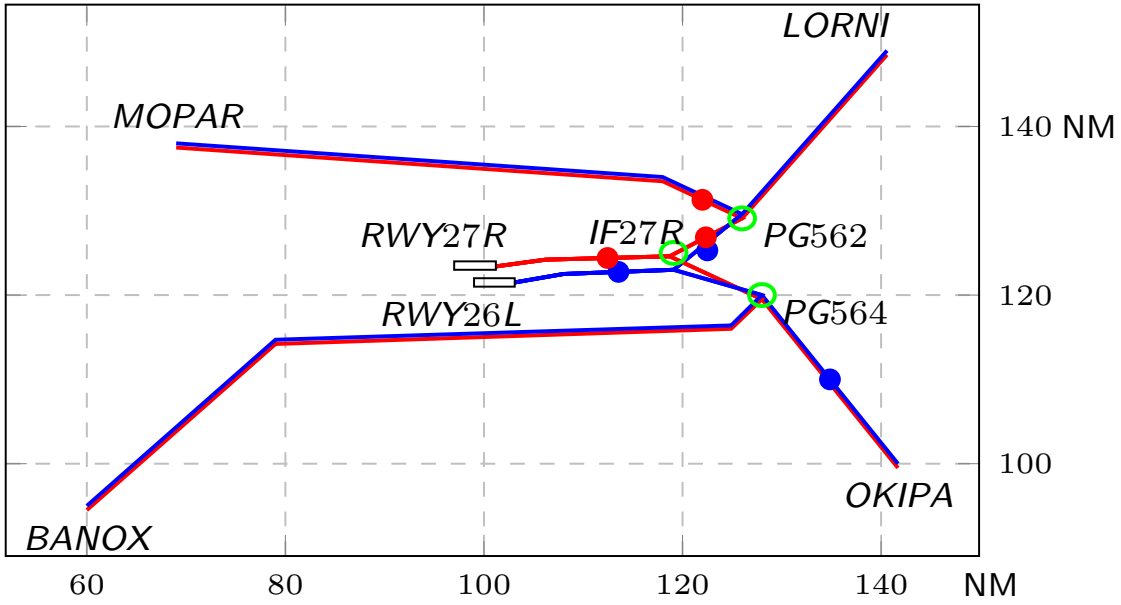
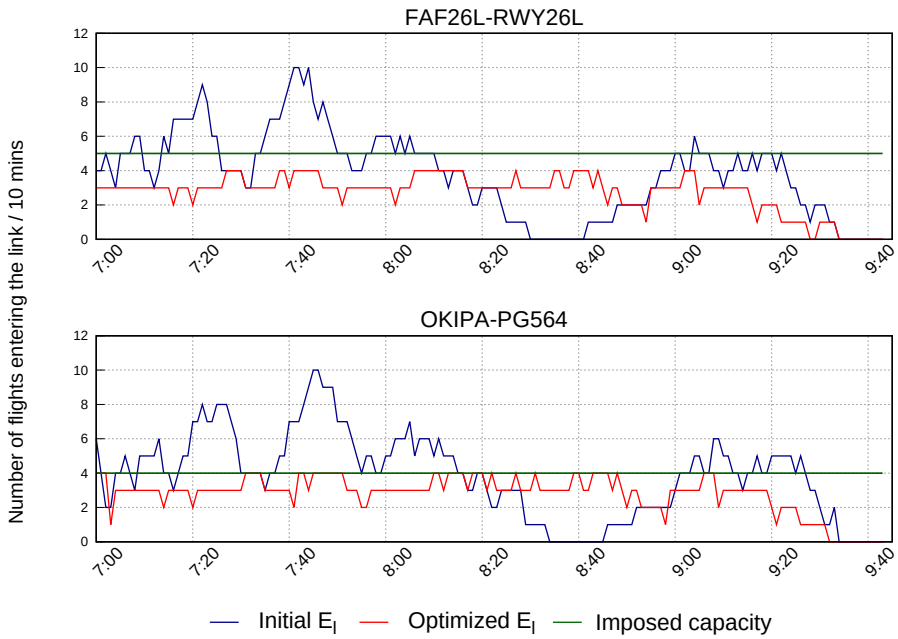
Case study

- Paris-CDG airport, real data of 18th February 2016 from 7:00 AM to 9:40 AM.
- Heavy and medium flights with a mix ratio of $23\% : 77\%$.

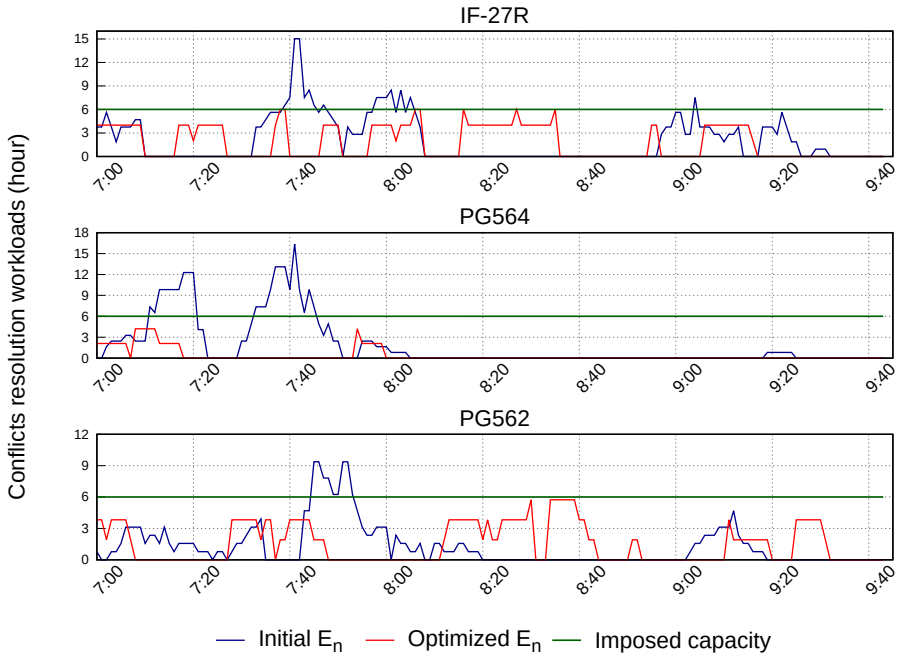


Link and node optimization results

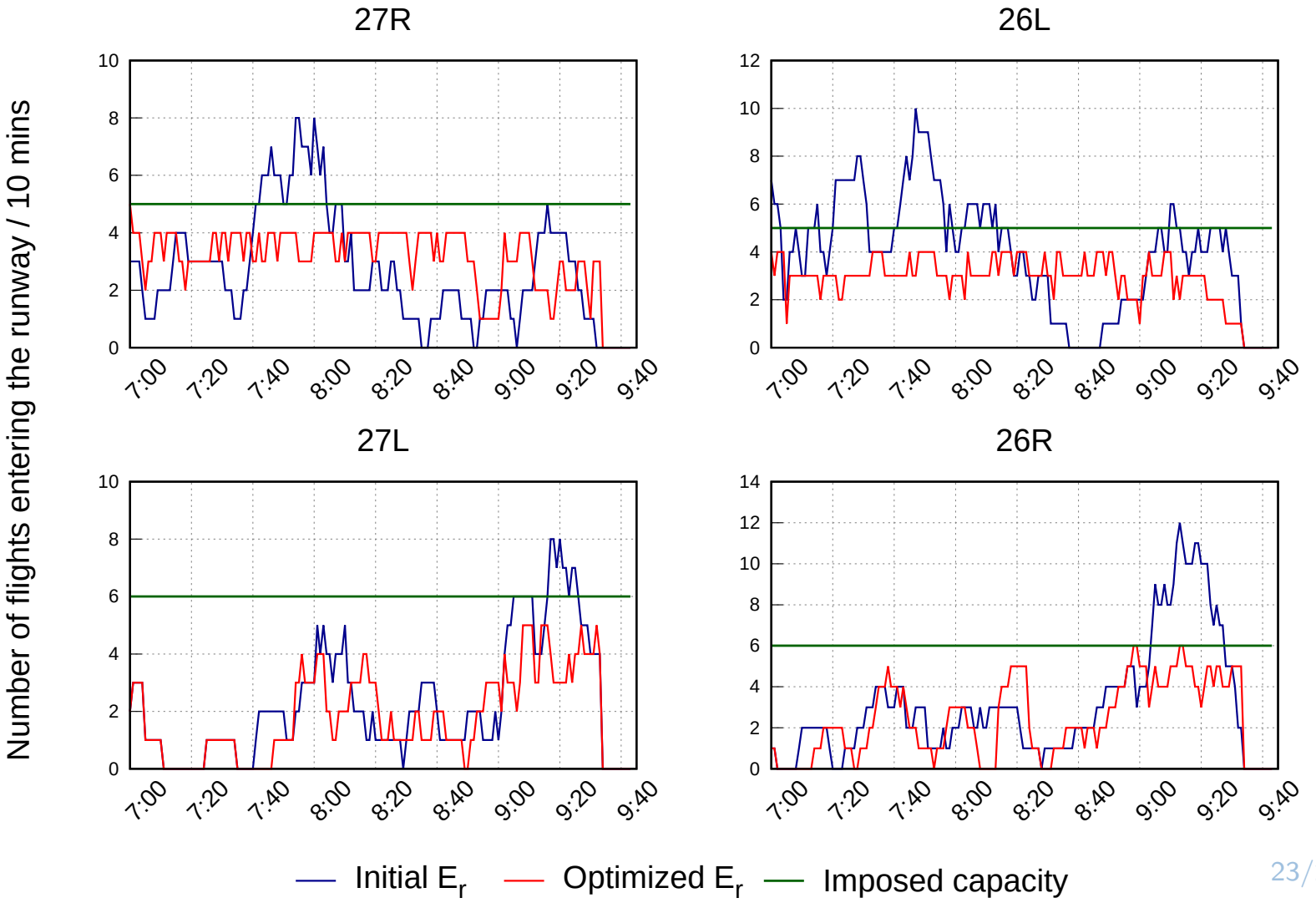
Link optimization results



Node optimization results

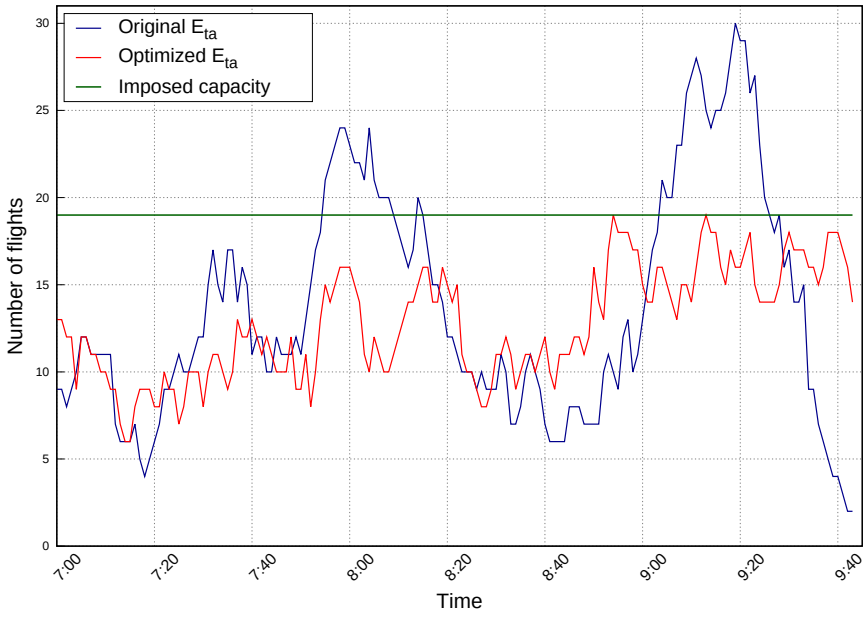


Runway optimization results

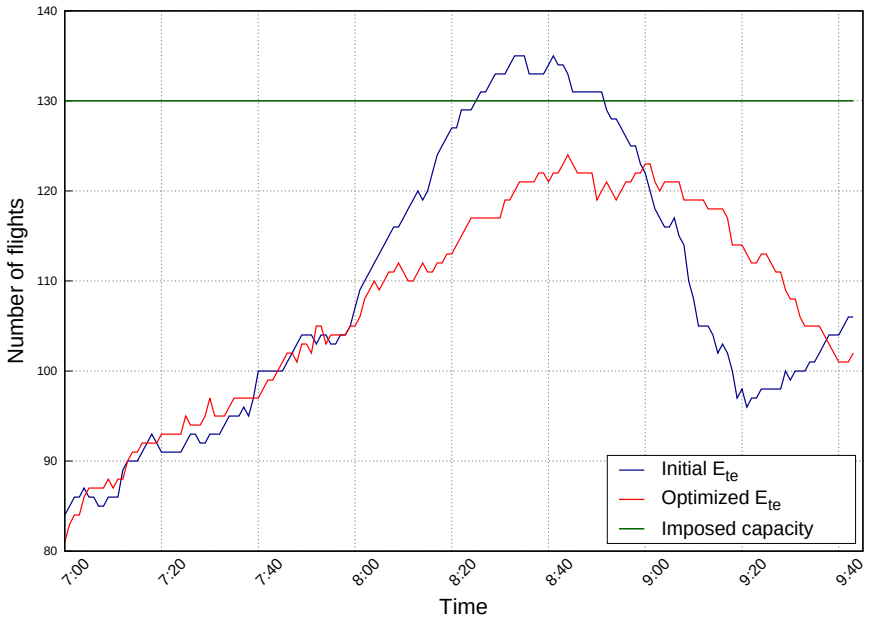


Terminal and taxiway occupancy

Taxiway



Terminal 2



Robustness test

- Reference case: flight by flight conflicts evaluation.
- Perturbations are implemented on TMA entry time.
- Average values of objective and sub-objectives of each model.

	Traffic flow-based model			Flight by flight conflict evaluation model		
	Perturbations			Perturbations		
Average congestion conflicts	± 0.5min	±1min	±2mins	±0.5min	±1min	± 2min
Node	6.585	10.1	16.56	21.07	44.882	78.37
Link	0.474	0.963	1.62	4.94	43.975	144.55
Runway	0	0.064	0.47	14.998	31.05	52.86
Taxiway	0	0.00134	0.033	0.519	0.596	0.835
Terminal	0	0	0	0	0	0
Sum	7.06	11.136	18.69	41.54	120.5	276.6

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Conclusions

An optimization approach to solve the integrated management problem of airport and terminal area on macroscopic level.

- Network abstraction.
- Traffic flow-based model.
- Adapted simulated annealing algorithm.

Mitigating the network congestion as well as the potential conflicts resolution workload in TMA.

Perspectives

- Test more scenarios with the proposed model.
- Extend the approach to multiple airports.

Thank you for your attention!