



Air Systems

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Increasing Air Traffic What is the problem?

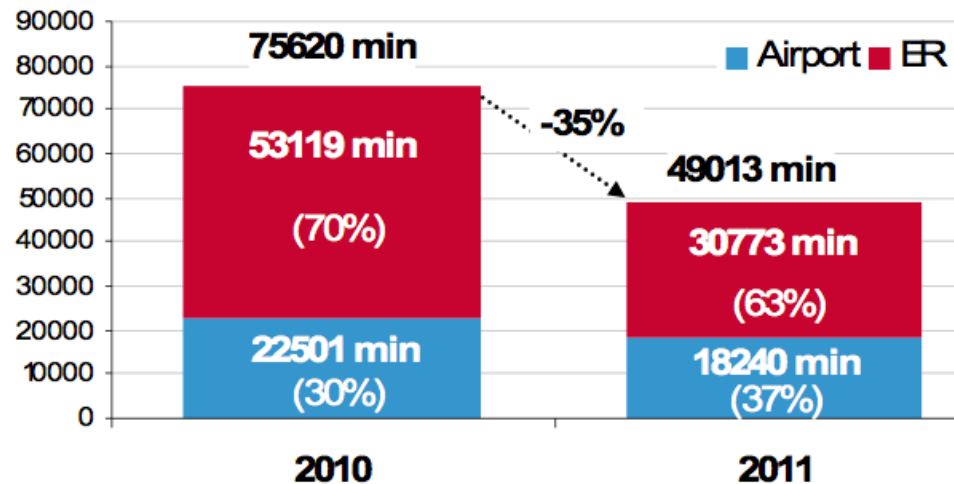
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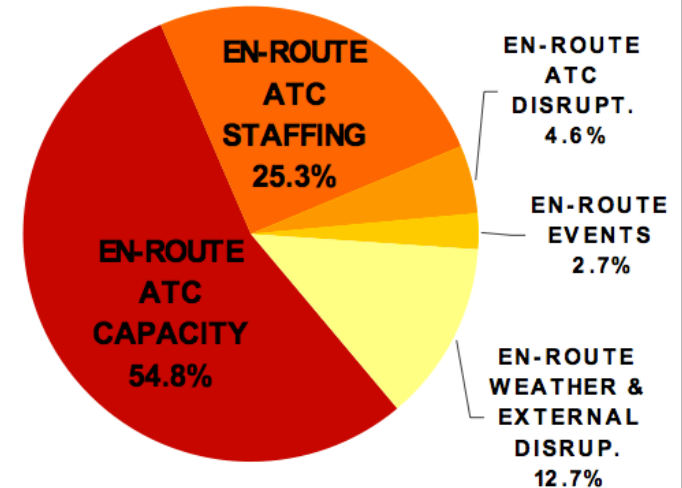
THALES

- **Description of the problem**
- **The proposed solution**
- **Uncertainty Model**
- **Application to the Air Traffic Management**
- **Questions to be answered**
- **Conclusion**
- **Questions**

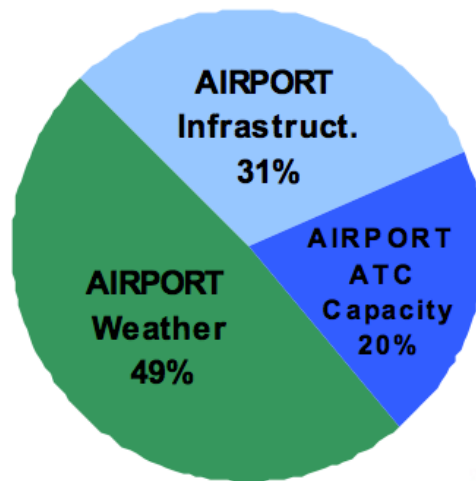
Avg. daily ATFM delays (min per day)



2011 En-route ATFM delay repartition



2011 Airport/TMA ATFM Delay Repartition



Source: Network Manager
Annual Network Operations Report 2011

- **Today in Europe:**

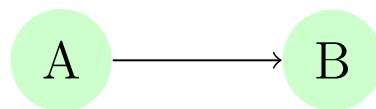
- ◆ Central Flow Management Unit is in charge of regulating the traffic with takeoff slots $[-5,10]$ minutes to ensure the respect of sector capacity constraint
- ◆ Air traffic controllers focus mainly on their sectors and the neighbors.
- ◆ DMAN system manages the sequencing at departure
- ◆ AMAN system manages the sequencing in the approach phase
- ◆ Uncertainty is not taken into account in the current systems and recently in the research literature on the Air Traffic Flow Management Problem

- **Enhance the strategic phase of the air traffic control by estimating the uncertainty and by optimizing the times of overflight on the waypoints.**
- **The purpose is to reduce the gap between air traffic control and air traffic management and also provide a common framework for the ground, approach and en-route phases.**
- **We assume that the controllers can play an important role to the regulation of air traffic in order that the capacities of sectors and airports are respected. (Air Traffic Flow Management)**
- **We propose a system that will generate a plan consisting of time of overflight on the coordination points for every flights. Then, parts of the plan are communicated to concerned controllers like objectives for the flights to be at a waypoint at a given time.**

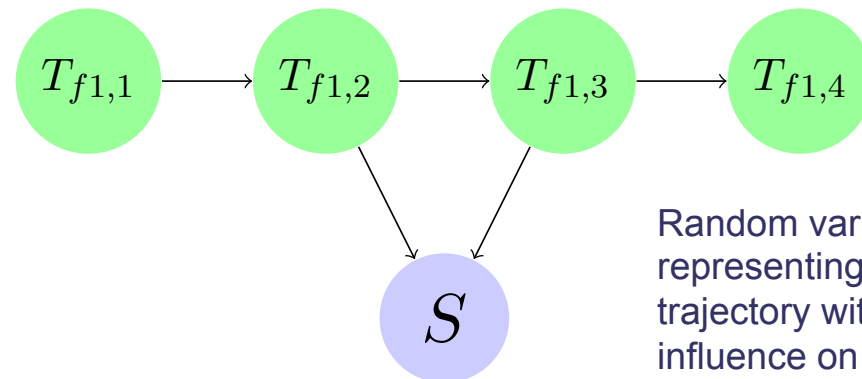


• The uncertainty is modeled through a Bayesian Network

- ◆ a.k.a Probabilistic directed acyclic graphical model
- ◆ Represents the conditional independencies between the random variables
- ◆ Useful to reduce the computational burden of the joint probability distribution



Two interacting
random variables



Random variables
representing a
trajectory with its
influence on sector
capacity

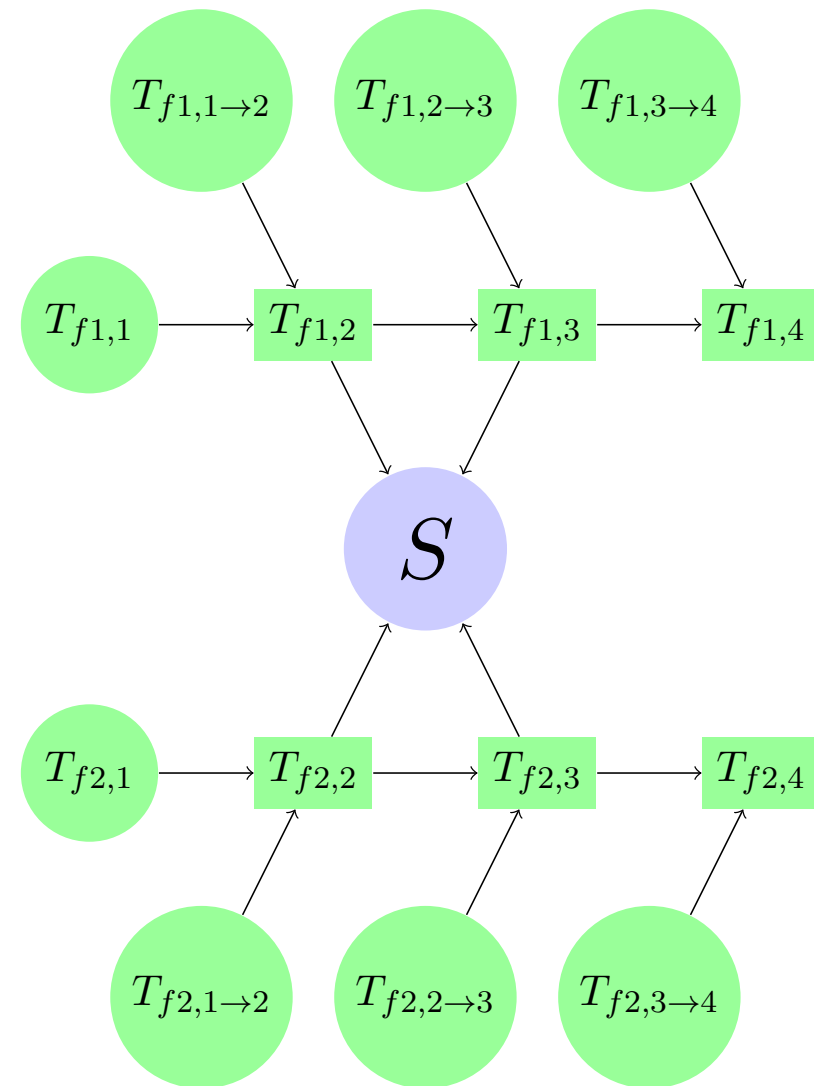
$$\begin{aligned}
 \Pr(A = t_a, B = t_b) &= \Pr(B = t_b | A = t_a) \Pr(A = t_a) \\
 &= \Pr(A = t_a | B = t_b) \Pr(B = t_b)
 \end{aligned}$$

Scenario:

- 2 Flights with the same Flight Plan (1-2-3-4)

Uniform Distribution Parameters

	Lower Bound	Upper Bound
1	-5	10
1-2	10	12
2-3	15	20
3-4	12	18



- Node of over flight: 1,2,3,4
- Node of traveling time: 1-2,2-3,3-4
- Node of sector capacity: S

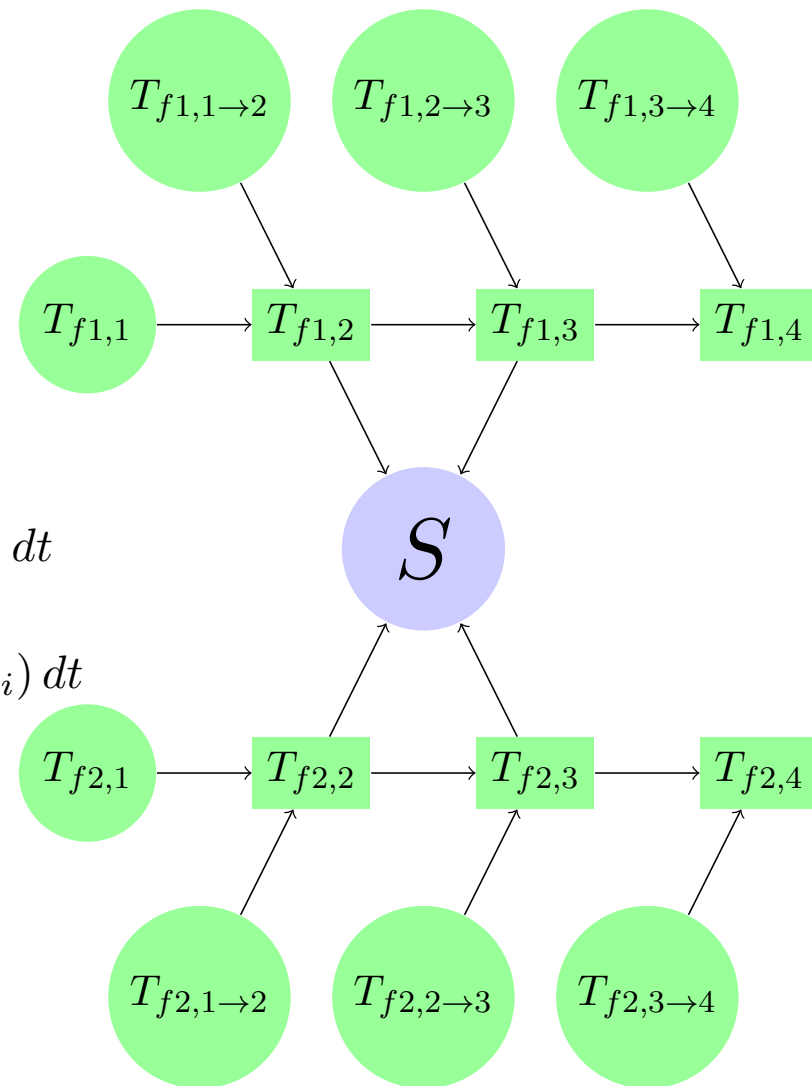
Assumption: Traveling time is independent of the time of arrival

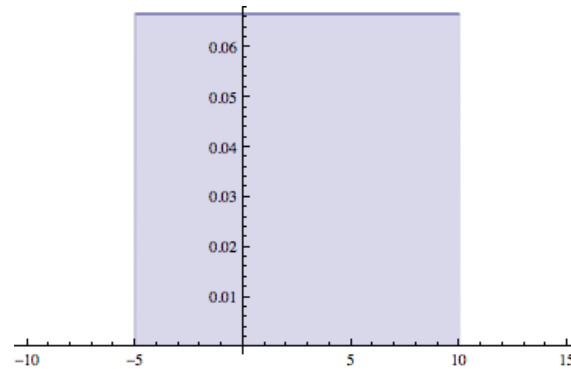
$$p_{T_{f,i+1}}(t_{f,i+1})$$

$$\begin{aligned}
 &= \int_{-\infty}^{\infty} p_{T_{f,i}, T_{f,i \rightarrow i+1}}(t_{f,i}, t_{f,i+1} - t_{f,i}) dt \\
 &= \int_{-\infty}^{\infty} p_{T_{f,i}}(t_{f,i}) p_{T_{f,i \rightarrow i+1}}(t_{f,i+1} - t_{f,i}) dt \\
 &= [p_{T_{f,i}} * p_{T_{f,i \rightarrow i+1}}](t_{f,i+1})
 \end{aligned}$$

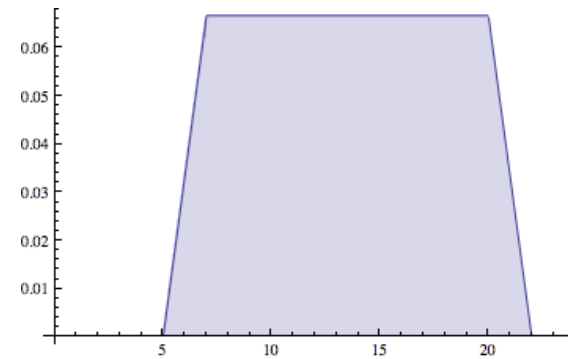
This is a convolution operation!

Thereafter, we can compute any marginal probability with convolution operations.

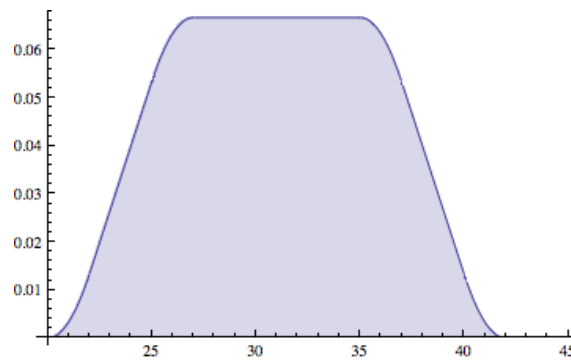




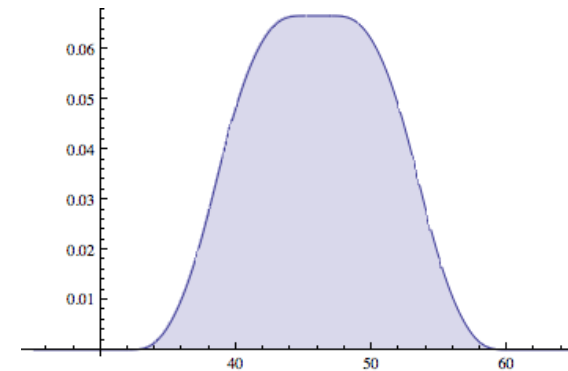
Prior on departure point



Resulting PDF on point 2



Resulting PDF on point 3



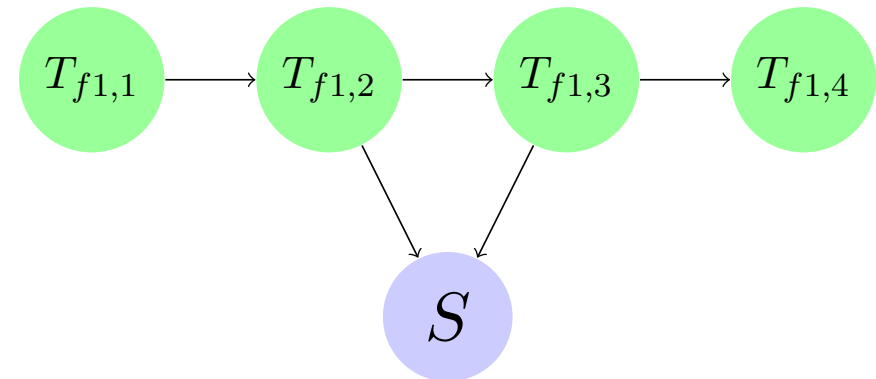
Resulting PDF on point 4

From this graph, how to compute the joint probability ?

$$\begin{aligned}\Pr(\cap_{i=1}^n T_{f,i}) &= \Pr(T_{f,1}) \prod_{i=2}^n \Pr(T_{f,i} | \cap_{j=1}^{i-1} T_{f,j}) \\ &= \Pr(T_{f,1}) \prod_{i=2}^n \Pr(T_{f,i} | T_{f,i-1}) \\ &= \Pr(T_{f,1}) \prod_{i=2}^n \Pr(T_{f,i \rightarrow i+1})\end{aligned}$$

Apply Chain Rule and Markov Assumption

Then, we can compute the most probable trajectory easily.



- **Probability for the flight i to **not** be in sector s during the interval $[t_0, t_1]$**

$$\begin{aligned}
 & \Pr(\overline{F_{i,s,[t_0,t_1]}}) \\
 &= \Pr(T_{i,2} > t_1) + \Pr(T_{i,3} < t_0) - \Pr(T_{i,2} > t_1, T_{i,3} < t_0) \\
 &= \Pr(T_{i,2} > t_1) + \Pr(T_{i,3} < t_0) \\
 &= \int_{t_1}^{\infty} p_{T_{i,2}}(t) dt + \int_{-\infty}^{t_0} p_{T_{i,3}}(t) dt
 \end{aligned}$$

- **Probability for the sector 1 to be congested**

$$\begin{aligned}
 & \Pr(C_{1,[t_0,t_1]}) \\
 &= \Pr(S_{1,[t_0,t_1]} > 1) \\
 &= \Pr(S_{1,[t_0,t_1]} = 2) \\
 &= [\Pr(F_{1,1,[t_0,t_1]})] [\Pr(F_{2,1,[t_0,t_1]})]
 \end{aligned}$$

- **If the sector interval is [10,20], the probability that the sector is congested is around 0.87.**
- **I fix my probability threshold at 0.75.**
- **Consequently, I can delay flight 2 with 2 minutes on the route 1-2 and then, the probability becomes 0.74.**



• Goal

- ◆ Model the uncertainty in the system and its evolution
- ◆ Take it into account in the decision process

• Intuition

- ◆ **Deterministic approach: Be there at this moment**
 - Probability one on the selected time slice
- ◆ **Robust approach: Be there at any time**
 - Probability of sector congestion must be equal to zero for every possible scenarios (Worst case)
- ◆ **Probabilistic approach : Somewhere between the two approaches**
 - I know how to estimate the probability that the constraint will not be respected and therefore, I can choose a low threshold.

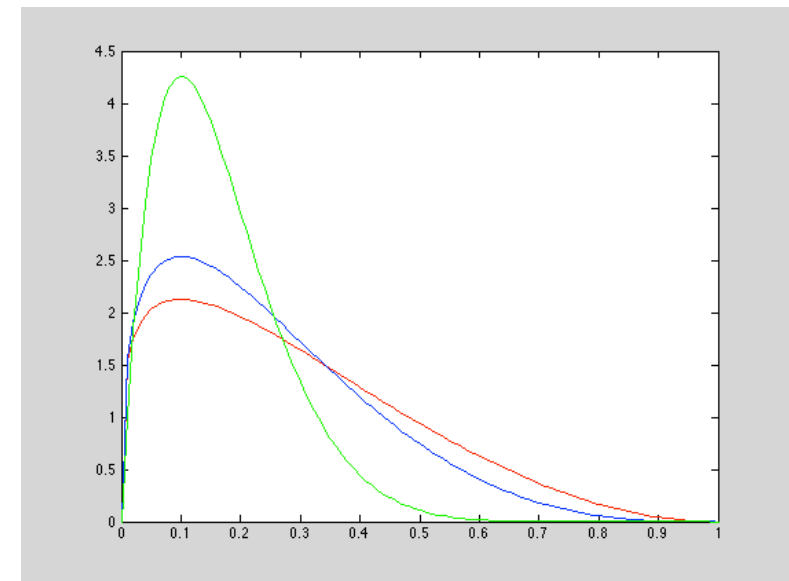


- **Doing the previous computation by hand is cumbersome**
- **We would like to define only the pdf on initial node and traveling nodes and have an algorithm to do the inference:**
 - ◆ **Monte-Carlo Simulation**
 - Forward Sampling (Relatively slow to convergence in mean and variance)
 - ◆ **More general formulation of the relationship between overflight node and sector node.**
 - We have some insights that this computation takes a combinatorial number of operations to determine the exact pdf.

- **With new observations, we can estimate better the pdf of the required time of traveling based on:**
 - ◆ **A local trajectory prediction**
 - ◆ **The last flight with the same flight plan (same day)**
 - ◆ **Historical data**
 - ◆ **4D trajectory**
- **Verify that the variance is decreasing with time**
- **Otherwise, there is a significant event (conflict avoidance, weather hazard,...) which requires that the aircraft deviates from the plan.**
- **Main research question: How to adapt the current plan to the new situation?**



- **Define formally the optimization problem**
 - ◆ Aggregate function?
 - ◆ Multi-criteria Optimization?
- **Decision variables: initial node and traveling nodes**
 - ◆ But we cannot change directly the pdf
 - ◆ Must use an intention operator
 - Necessary to model uncertainty of the flight intent and the aircraft capacity



- **Cost function: Expected cost of delays**
 - ◆ **Aggregation over all aircraft (with priority)?**
- **Constraint: Capacity constraints on the sector**
 - ◆ Expected cost of congestion (Soft constraint)
- **Which optimization algorithm to use ?**
 - ◆ **Evolutionary Algorithm**
 - Adapted to operator based optimization
 - But population-based algorithm must take into account the Monte-Carlo step in the evaluation of the cost function!
 - Nevertheless, the population represents different scenarios

Thank you for your attention

Questions or comments ?