Towards an Operational Sectorisation based on Deterministic and Stochastic Partitioning Algorithms

Application to the French airspace LFEE (Reims)

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Towards an Operational Sectorisation based on Deterministic and Stochastic Partitioning Algorithms

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Sectorisation problem

I'm a FMP. I group elementary sectors (ES) to form control sectors (CS).

► FMP: Flow Management Position
► From Short-Term Planning to Pre-Tactical
► Sector configuration = set of CS for a given period of time.
Motivation

Tch, tch ! These same old manual methods from the 20th century...

What about flexible and modular dynamic airspace configurations?
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Ambitions

Hi, I have plenty of scientific methods to help you.

Hmm... OK, but I want conventional sectors and stability over time!

SESAR
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Model - Graph $G = (V, E)$

- $V$ the set of building blocks
- $E$ the set of edges (direct trajectories between two blocks)
- $D_v(\delta t)$ density for vertex $v$ during $\delta t$
- $C_e(\delta t)$ coordination for edge $e$ during $\delta t$
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Partition and constraints

\[ P_k(\delta t) = S_1, \ldots, S_k \]

\[ S_1 = LFEHHBN = \{LFEUB, LFEHN\}, S_2 = \ldots \]

\[ \forall i \in 1, \ldots, k, S_i \neq \emptyset \]

\[ \forall i, j \in 1, \ldots, k, i \neq j, S_i \cap S_j = \emptyset \]

\[ \bigcup_{i \in 1, \ldots, k} S_i = E \]

\[ \forall i \in 1, \ldots k, S_i \text{ satisfies the } \textit{connectivity} \text{ constraint} \]
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Balance objective

Balance objective:

\[
\text{balance}(P_k(\delta t)) = \sum_i D_{S_i}(\delta t) - \frac{\sum_i D_{S_i}(\delta t)}{k}
\]

where \(D_{S_i}(\delta t) = \sum_{v \in S_i} D_v(\delta t)\)

\[
\sum_i D_{S_i}(\delta t) = 7.3
\]

balance(\(P_6\)) = 15.7

Definitions:

- Balance objective
- Shortest path problem
- Multi-objective optimization
- Genetic algorithm
- Sectorisation
- Deterministic partitioning
- Stochastic partitioning

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Cut objective

Definition

\[
cut(P_k(\delta t)) = \sum_{i<j} \text{cut}(\delta t, S_i, S_j)
\]

where

\[
\text{cut}(\delta t, S_i, S_j) = \sum_{v_1 \in S_i, v_2 \in S_j} C(v_1, v_2)(\delta t)
\]
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Compactness objective

![Image of sectorisation]

**Definition**

\[
\text{compactness}(P_k(\delta t)) = \prod_i \text{compactness}(S_i)
\]

where \( \text{compactness}(S_i) = \frac{\sum j \text{ prisms of } S_i \text{ volume}(j)}{\text{volume}(\text{cover}(i) \cap \text{ACC})} \)

\( \text{cover}(i) \) is the smallest prism which includes all the prisms of \( i \)
Other objectives that may be considered

- the total number of re-entries
- the total number of short transits
- the total number of overloads
- ...

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Determining all conventional solutions

Exhaustive search tree

- Combining conventional sectors
- Use of cut rules to rapidly explore the tree
  - \( \exists i, j \in 1, \ldots, k, S_i \cap S_j \neq \emptyset \)
  - \( \bigcup_{i \in 1, \ldots, k} S_i = E \)
  - Remaining nodes will not ensure \( \bigcup_{i \in 1, \ldots, k} S_i = E \)

Applications

- Reims (LFEE) - 21 ES - 58 CS - 17 positions - \( 1.8 \times 10^5 \) conventional sector configurations / \( 4.7 \times 10^{14} \)
- Brest (LFRR) - 32 ES - 114 CS - 18 positions - \( 1.9 \times 10^8 \) conventional sector configurations / \( 1.3 \times 10^{26} \)
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Assessing configurations - Pareto-optimal solutions

We keep solutions from the first Pareto fronts.
Now, can I also propose non conventional sectors?

OK, but only if I can decide to integrate them or not in my catalogue.
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Simulated Annealing optimisation

Disorganising

\[
\min \left( \alpha \text{cut}(P_k) + \beta \text{balance}(P_k) + \frac{1}{\text{compactness}^2(P_k)} \right)
\]

Reforming

\[
\min \left( \frac{1}{\text{compactness}(P_k)} \right)
\]

such that \( \text{balance}(P_k) \leq \text{balance}(P_{k,\text{initial}}) \)

\( \text{cut}(P_k) \leq \text{cut}(P_{k,\text{initial}}) \)
Stabilising over time

And we favor collapsing / decollapsing operations.
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Comparison to the sector configuration plan of a very busy day of traffic (2015, June 26th).
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An initial solution and its refinement

Conventional sector configuration

Balance: 16.02
Cut: 121.03

→ 8.434
→ 111.28

Refined sector configuration
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Balance along the day

Average gain : 12.9%
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Cut along the day

Average gain : 3.4%
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Cell-based distance along the day

Cell-based distance along the day

OperationalPlan_m1
OptimizedPlan_bestBalance_m1
OptimizedPlan_smooth_m1

Value
0 5 10 15 20 25 30 35 40 45 50 55 60

Time
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Conclusion and perspectives

- We can improve the workload distribution while
  - keeping compact sectors
  - ensuring stability over time

- Integrated to a decision support tool

Perspectives:

- Improving objectives such as
  - workload distribution
  - overloads

- Determining the opening times
- Increasing the number of blocks
- Using multi-objective techniques to refine
Questions?

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