RECIFE: a MCDSS for Railway Capacity

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Objectives of RECIFE project

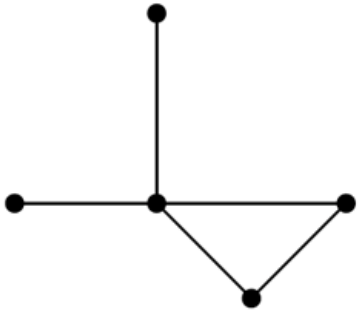
Research project with INRETS and SNCF:

- Models and algorithms to evaluate railway infrastructure capacity
- Tools integrated in a decision support software
- Application on
  - Pierrefitte-Gonesse node (junction)
  - Lille-Flandres (station)

1. **Railway Infrastructure Operation Planning**
2. **Information System**
3. **Screenshots**
4. **Conclusion**

1.1 Problematic: a railway planning problem (RPP)

- Planning the construction or reconstruction of infrastructures



1.1 Problematic: a railway planning problem (RPP)

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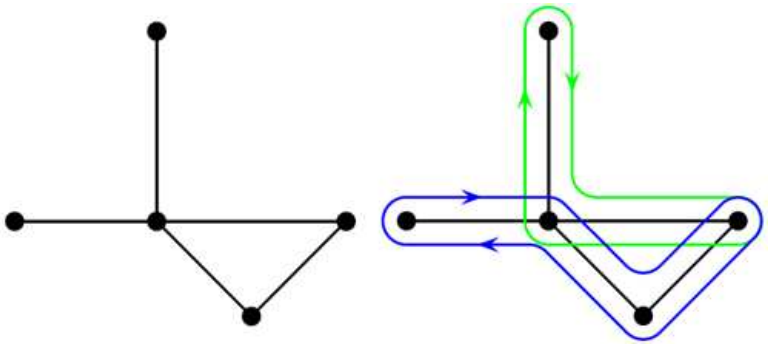

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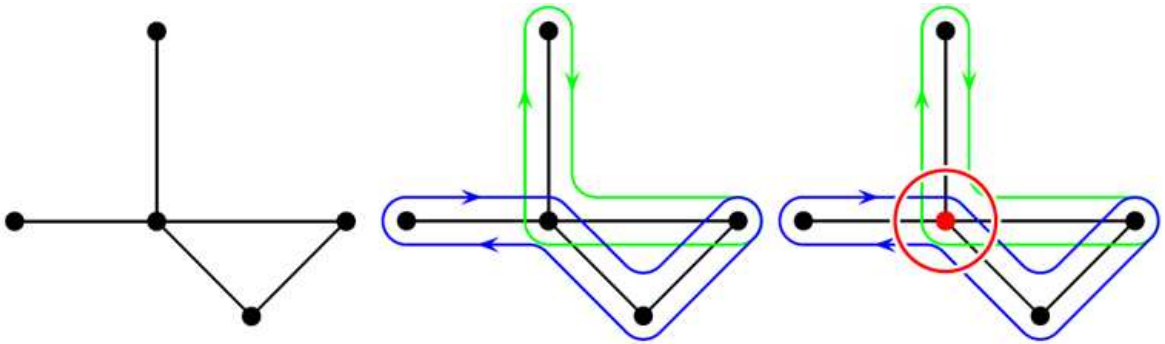
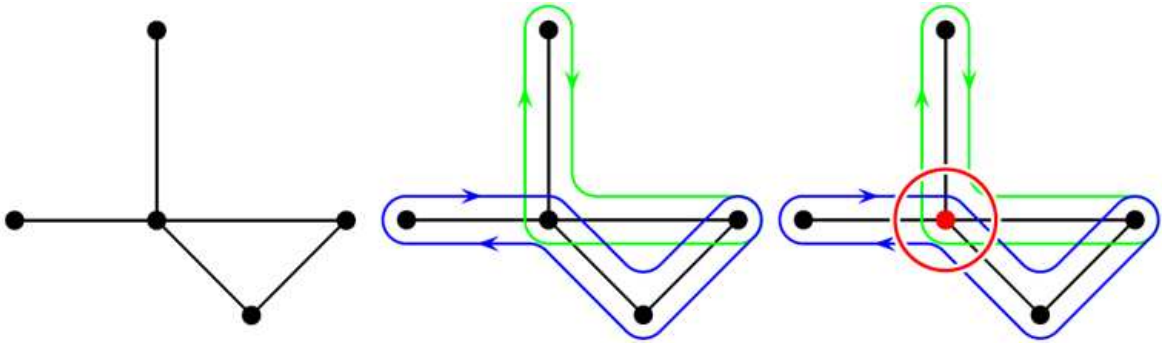


1.1 Problematic: a railway planning problem (RPP)

- Planning the construction or reconstruction of infrastructures
- **Capacity of one component / junctions of a rail system**



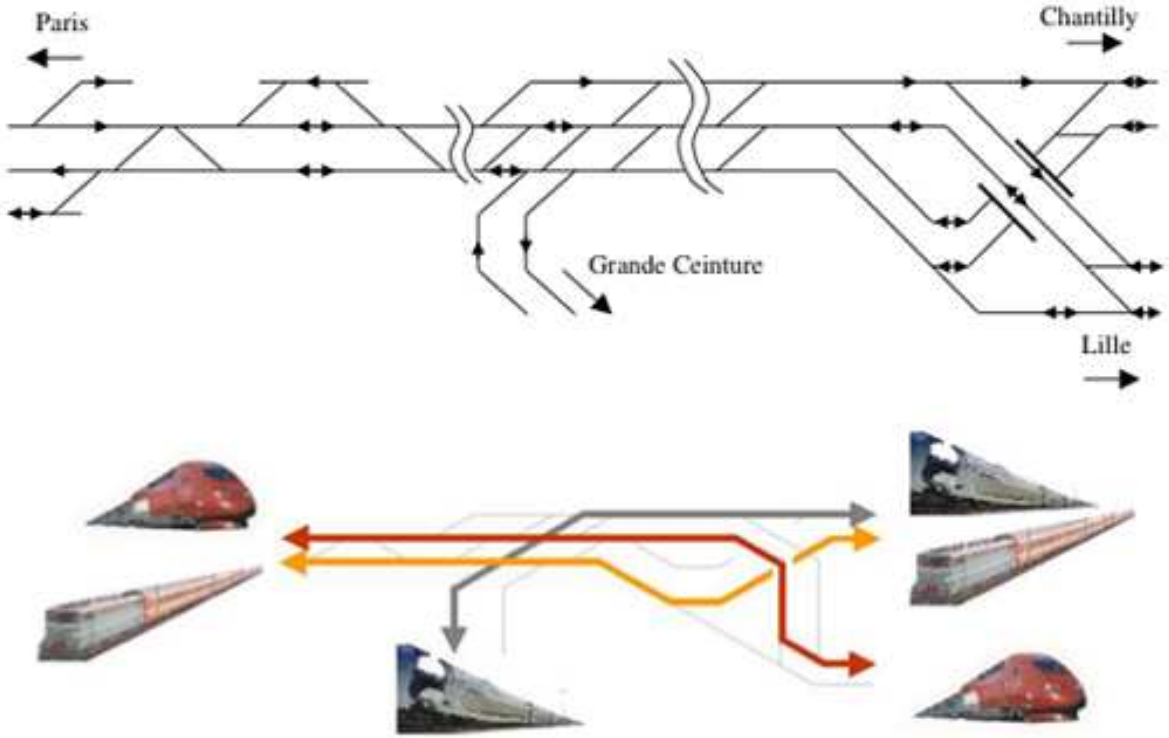
$+ \left\{ \begin{array}{l} \text{Safety rules} \\ \text{Rolling stock technical characteristics} \\ \text{Service quality} \end{array} \right.$

How many trains can be routed through the junction within a time interval?

What is the best solution to route these trains?

1.1 Problematic: a railway planning problem (RPP)

- Planning the construction or reconstruction of infrastructures
- Capacity of one component / junctions of a rail system
- Junction Pierrefitte-Gonesse, north of Paris



1.2 Decision process

- Helping the decision-maker (expert in railway management) to answer to
  - **the feasibility and/or saturation problem**

  plus
  - **the stability problem** (ability to absorb delays)

- Decision process structured lexicographically by two criteria:
  - 1st criterion:
    max the number of train
  - 2nd criterion:
    max the stability among the equivalent timetables
    (minimize the sum of delays)

1. Railway Infrastructure Operation Planning
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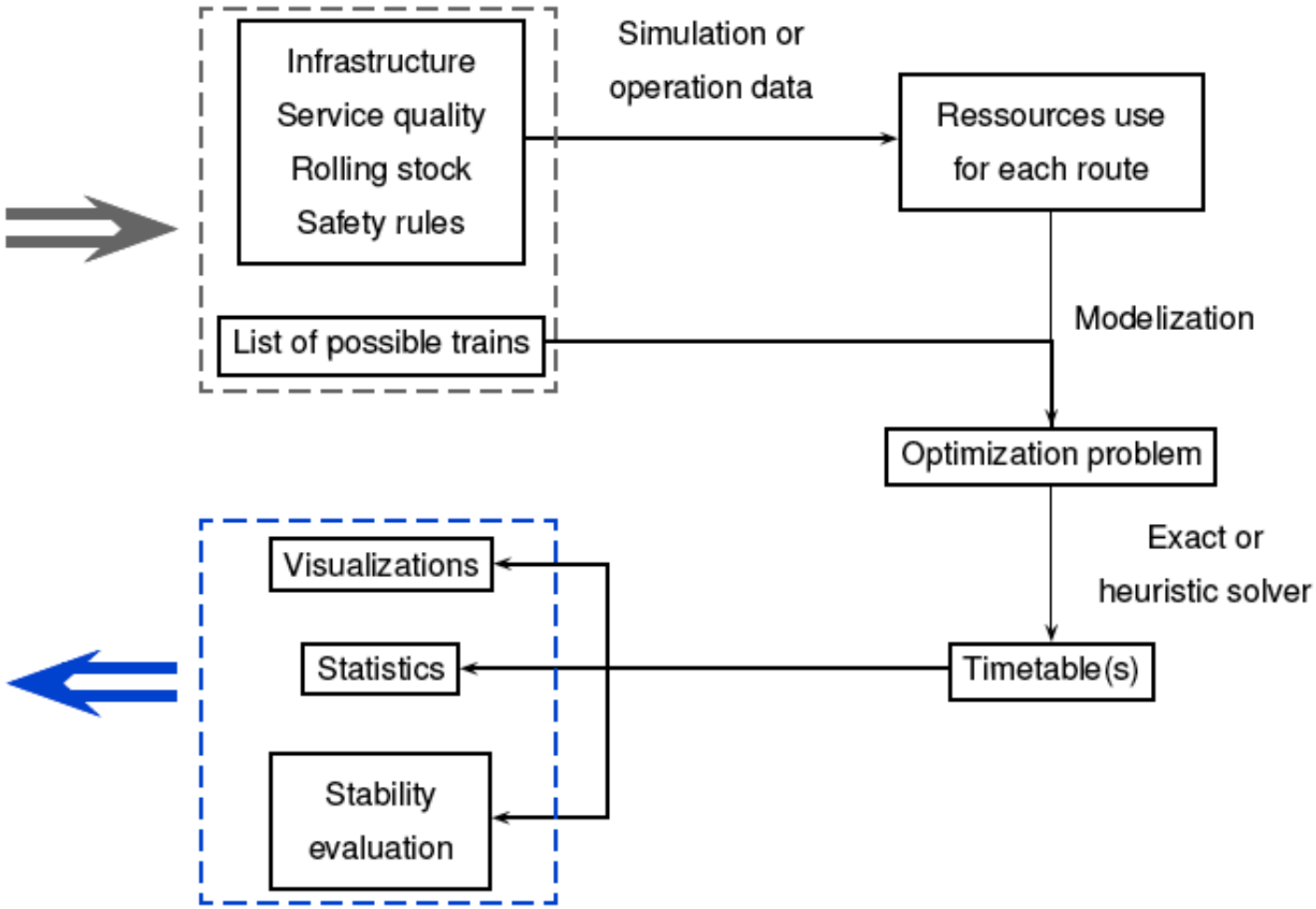
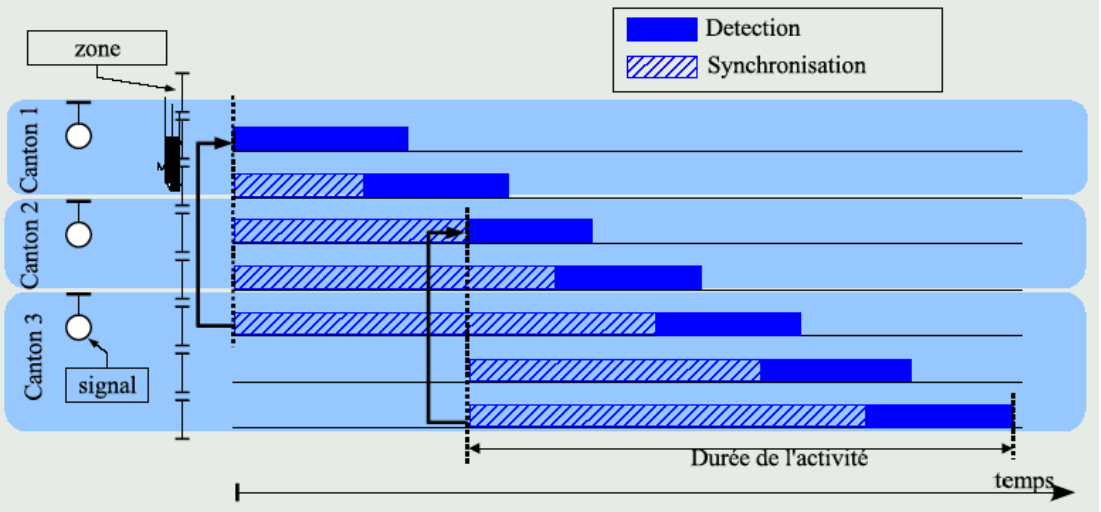
2.1 Organisation of the information system



2.2 Input data: one situation

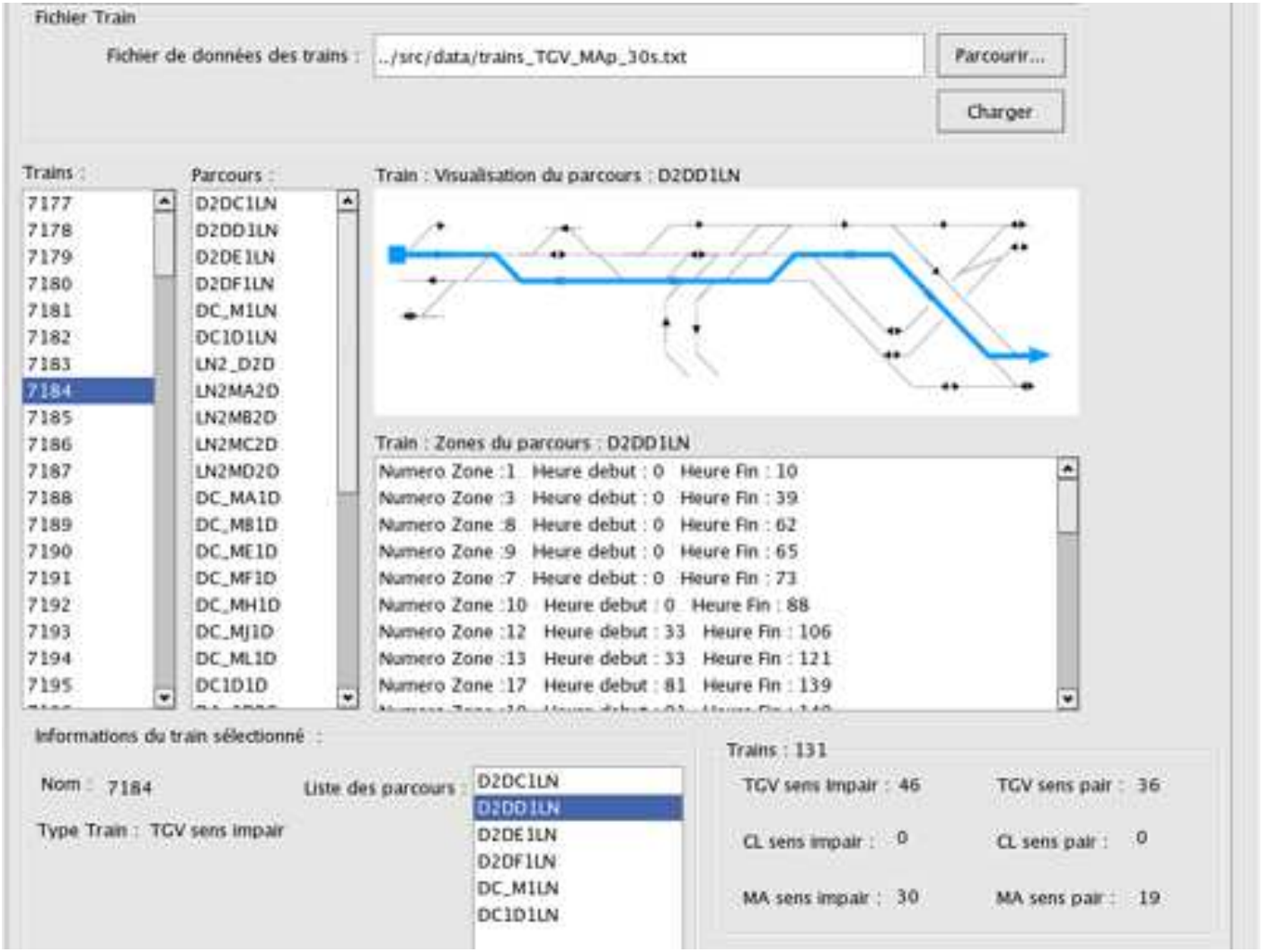
Kind of traffic, time-windows in the day, density, etc.

- Data (infrastructure, service, rolling stock, safety rules)
  - All possible routes are given
  - All possible arrival-date are given
  - Resource comsumed:



- One list of trains

2.2 Input data: one situation



2.3 Handling the first criterion: optimization stage

Given

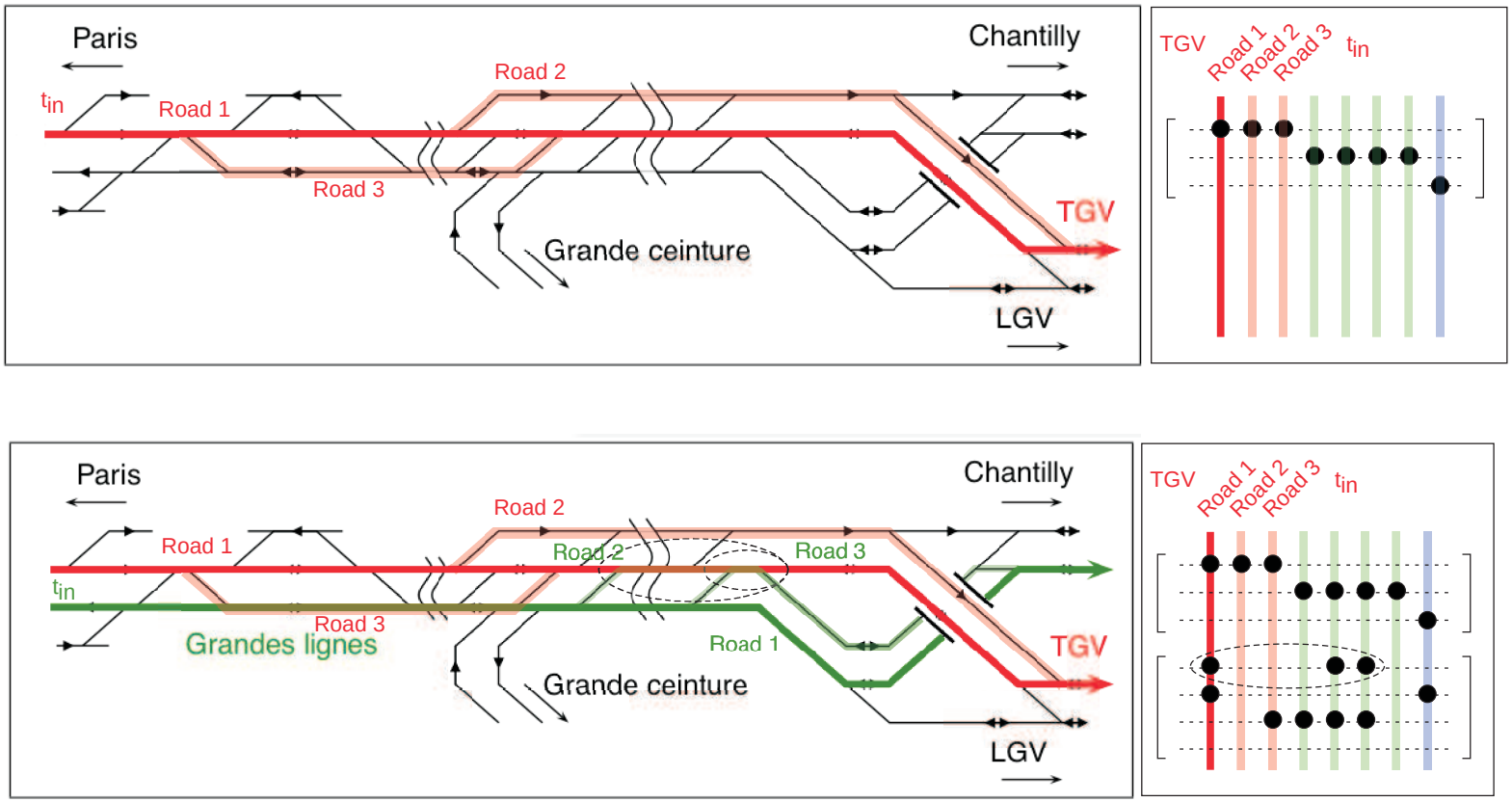
- a finite set $I = \{1, \ldots, n\}$ of items
- $\{T_j\}, j \in J = \{1, \ldots, m\}$, a collection of m subsets of I

a packing is a subset $P \subseteq I$ such that $|T_j \cap P| \leq 1, \forall j \in J$ which

$$\left[\begin{array}{ll} Max\ z(x) = & \sum_{i \in I} c_i x_i \\ & \sum_{i \in I} t_{i,j} x_i \leq 1, \forall j \in J \\ & x_i \in \{0,1\} \quad , \forall i \in I \\ & t_{i,j} \in \{0,1\} \quad , \forall i \in I, \forall j \in J \end{array}\right] \quad (SPP)$$

- Set Packing Prb (SPP): strongly NP-Hard (Garey and Johnson 1979)
- Solvers: exact, Cplex; metaheuristics, GRASP; ACO

2.3 Handling the first criterion: optimization stage



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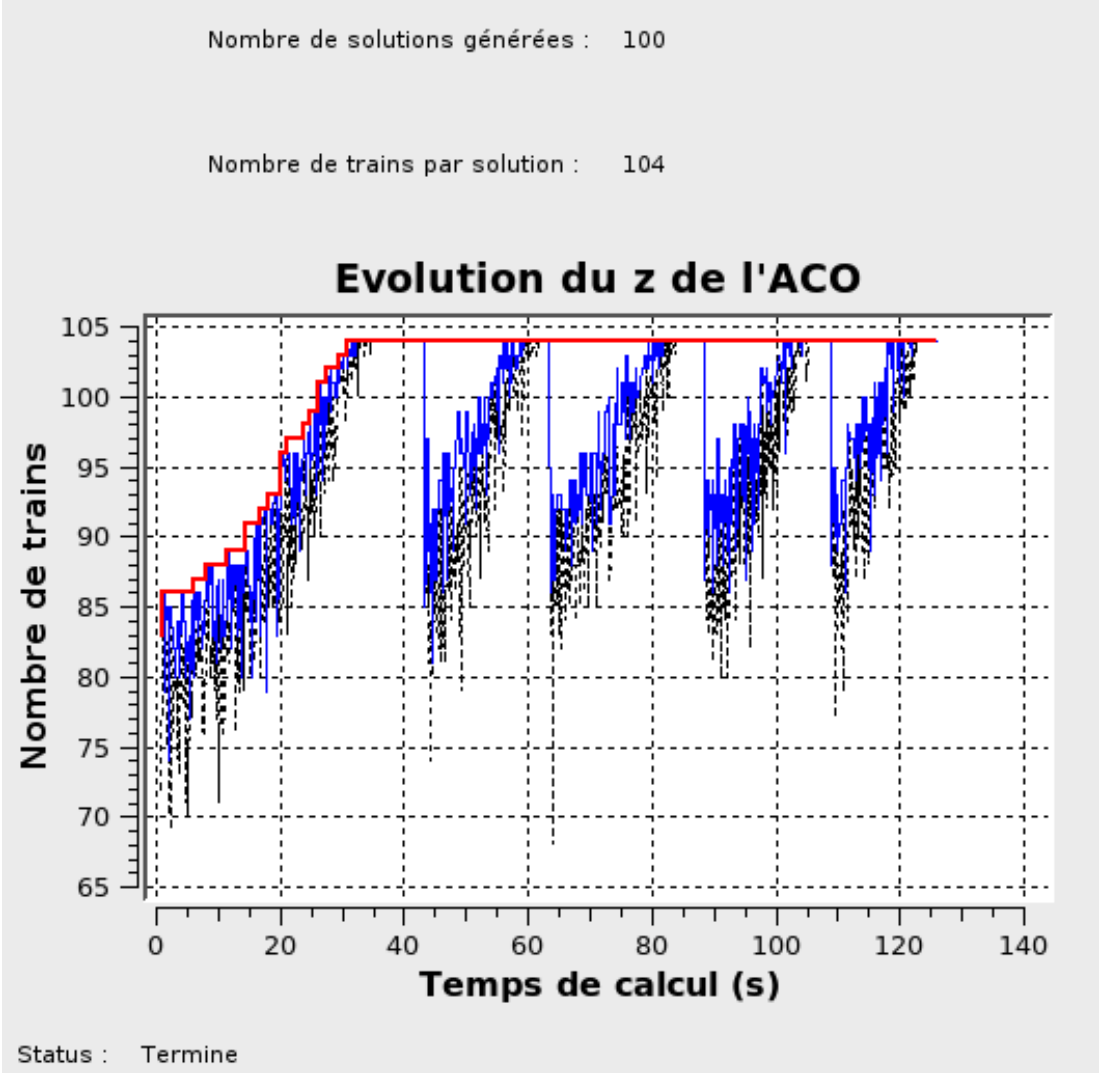
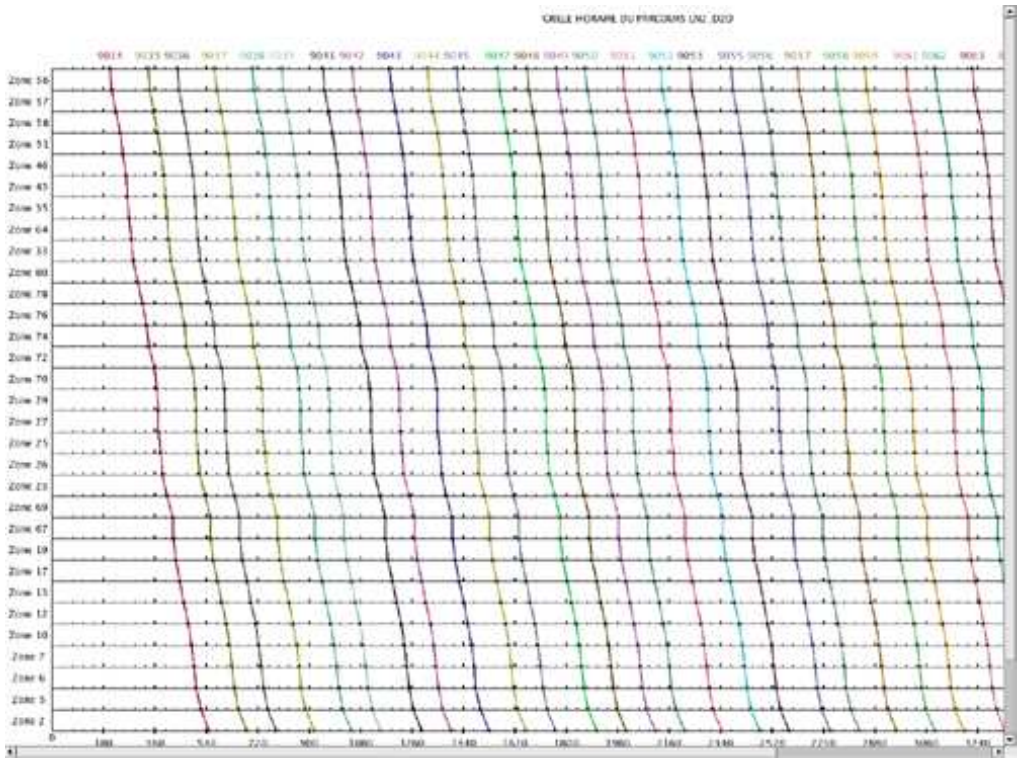


2.4 Data in output

A solution: a list $\mathcal{L}$ of timetables

- equivalent timetables: same number of trains
- different timetables: infrastructure used, trains selected (saturation), etc.



2.5 Handling the second criterion: simulation stage

The simulation and analysis modules: help the decision-maker

- **to evaluate the stability of the generated timetables**
- **to determine the critical items**

Principle (1/2): **delay propagation**

- Two types of delay
  - primary delay caused by a disruption
  - secondary delay due to interactions between trains
- Impact of a primary delay
  - secondary delays generated directly or indirectly
  - only short primary delay considered
- Processing the conflicts
  - arrival-date of other trains delayed
  - routes and schedules maintained (no re-optimization)

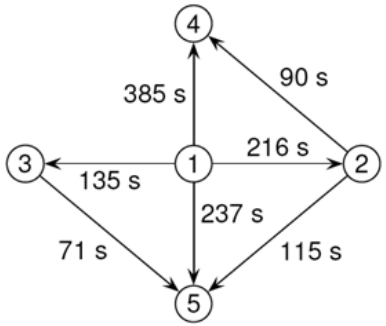
2.5 Handling the second criterion: simulation stage

Principle (2/2): **delay propagation**

- Measure the effect
  - Domino effect: sum of secondary delays of a primary delay
  - Series of shortest path computation

Illustration: didactic example on Pierrefitte-Gonesse node:

- 5 trains routed, 12 different timetables generated
- Stability evaluation:
  - One graph of potential direct conflicts for each timetable:



  - 2 primary delay values (180s & 300s). For the primary delay of 180s:

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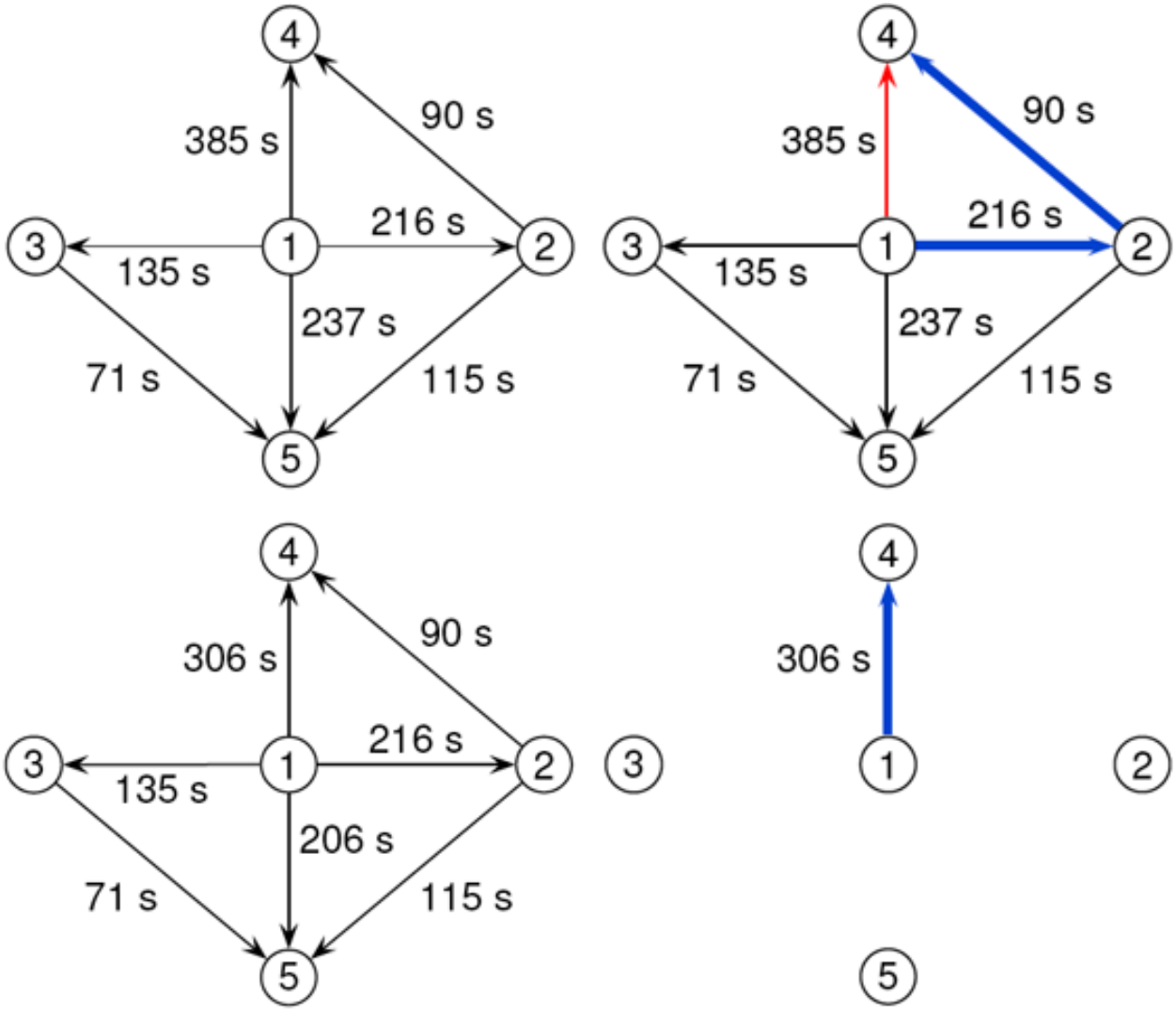

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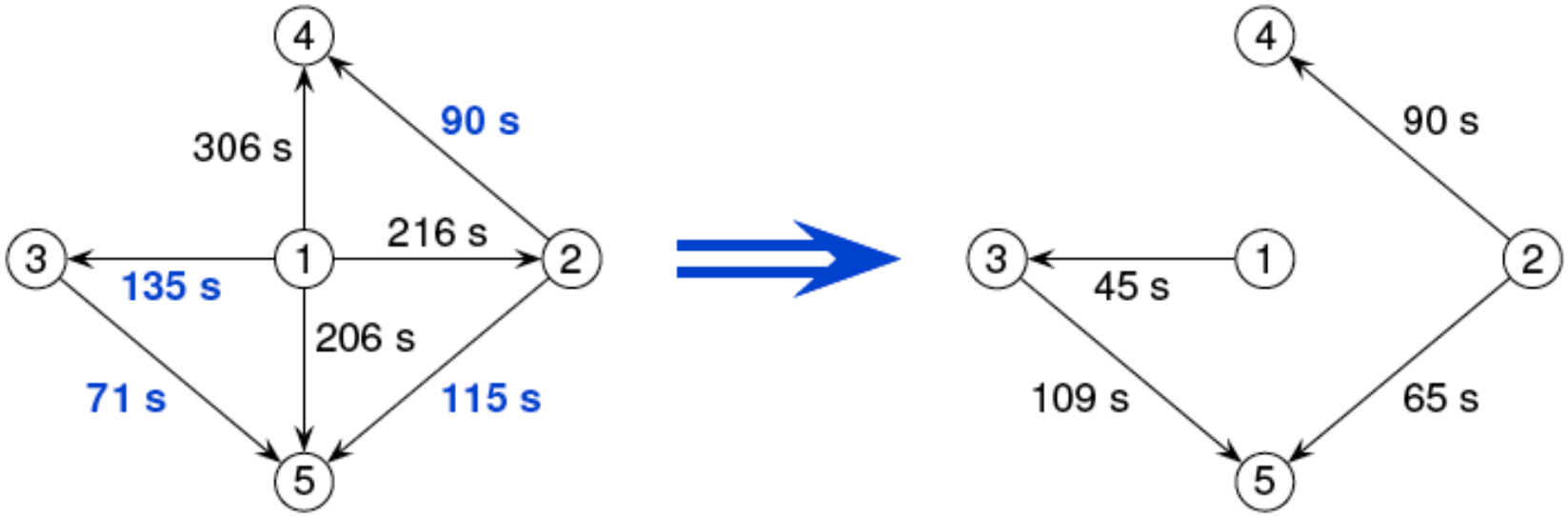
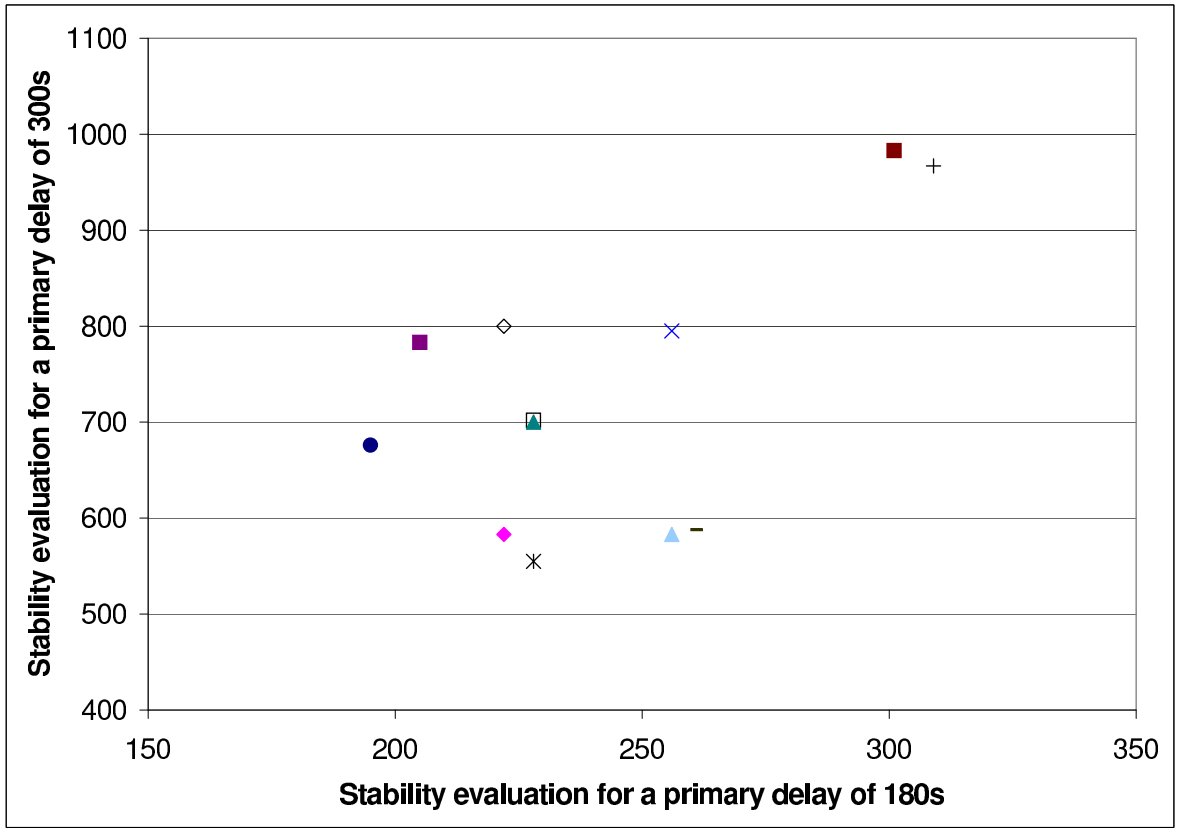


Total delay generated by train 1	:	45 s
Total delay generated by train 2	:	155 s
Total delay generated by train 3	:	109 s
Total delay generated by train 4 and 5	:	0 s
Stability evaluation	=	**309 s**

2.5 Handling the second criterion: simulation stage

Representation in the outcome space



12 timetables $\Rightarrow$ 3 potentially efficient solutions

2.5 Handling the second criterion: simulation stage

Principle: **the DM simulates the effect of delays (1/2)**

- to assess the stability:
  - **primary delay ≈ one objective**
  - **set of objectives "dynamically" defined (what-if)**
  - **analyse of "efficient" timetables**
    - **visual analyse**
      - global comparizon (performances in the outcome space)
      - local comparison of k-efficient sols (perfs on criteria)
    - **quantitative analyse**
      - pairwize comparison (solutions)
      - statistics of resources used (solution)
      - statistics on delay propagated [critical train] (solution)

2.5 Handling the second criterion: simulation stage

Principle: **the DM simulates the effect of delays (2/2)**

- to catch the "uncertainty/incompleteness" of the information (data, model) handled:

  in the objective space, analyse the solutions of rank > 1

- to validate a solution in its technical environment

  a solution is viewed inside the usual graphics handled by the DM (space-time graphic, gantt chart, simulation of traffic on the infrastructure)

Data in output: **one realistic timetable,**

which maximizes the number of trains using the infrastructure,
for the given scenario of traffic,
with a good stability faced to possible delays

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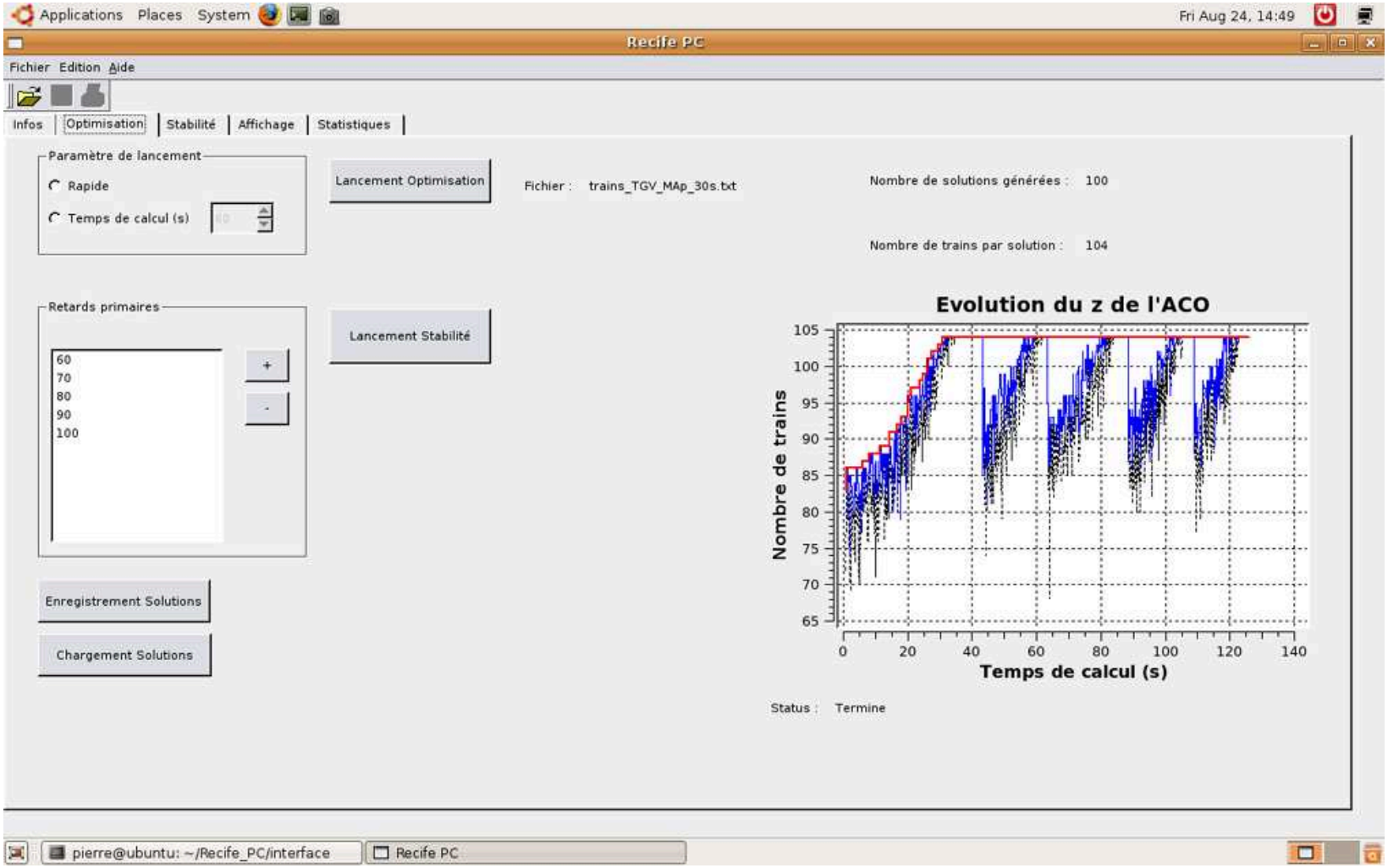
3.1 Screenshots: focussed on the MCDM aspects



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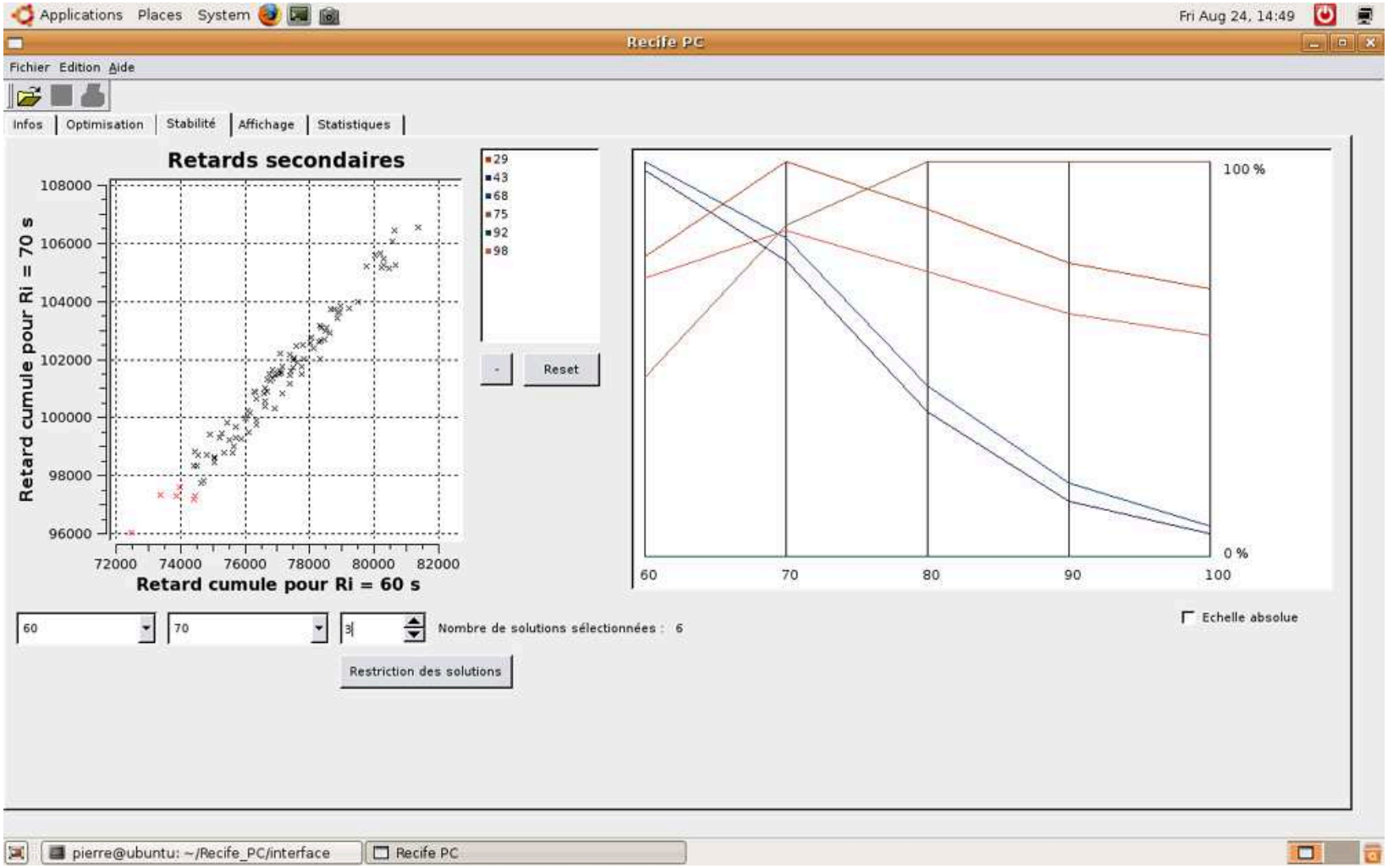
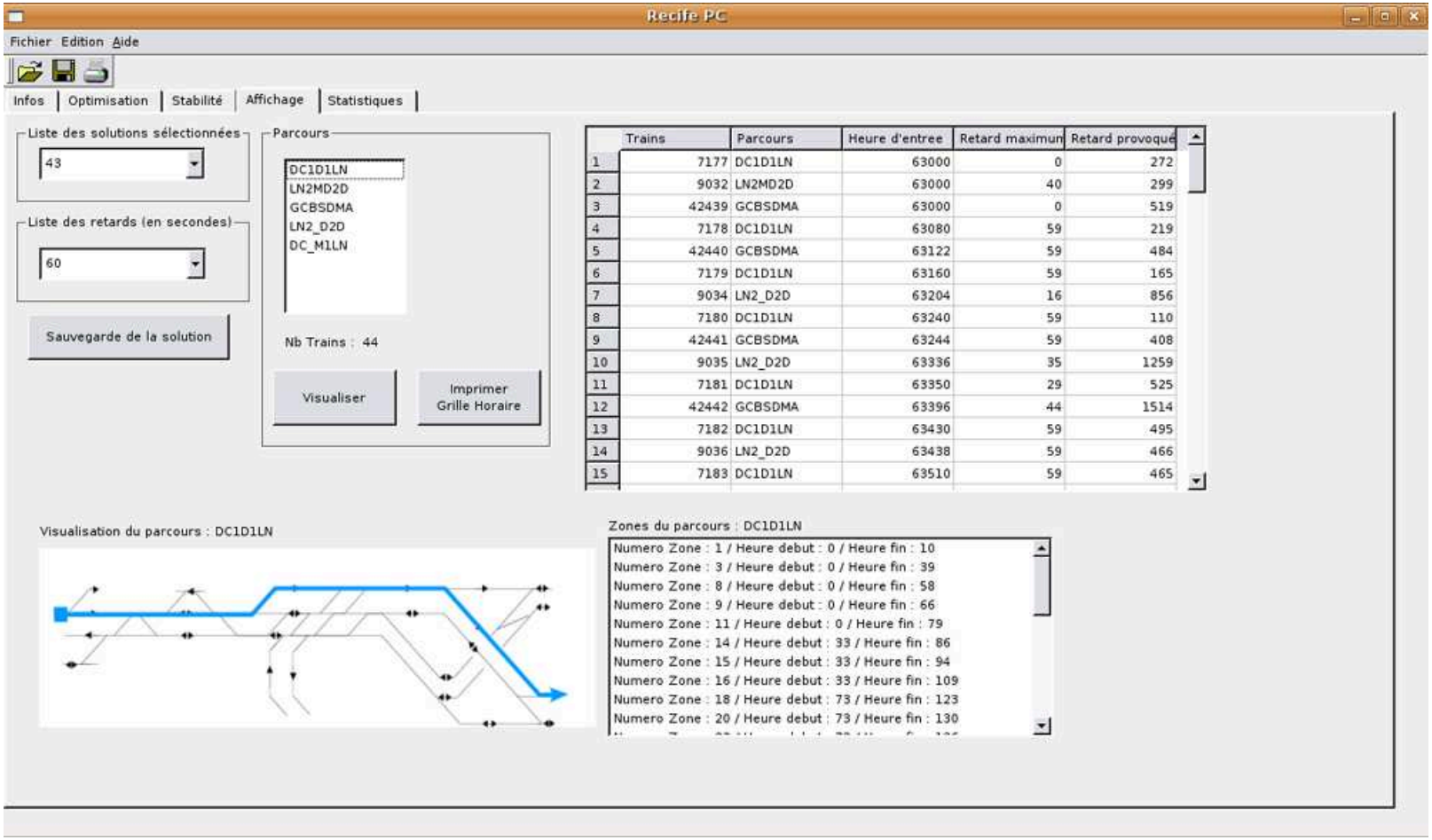


3.2 Screenshots: focussed on a solution



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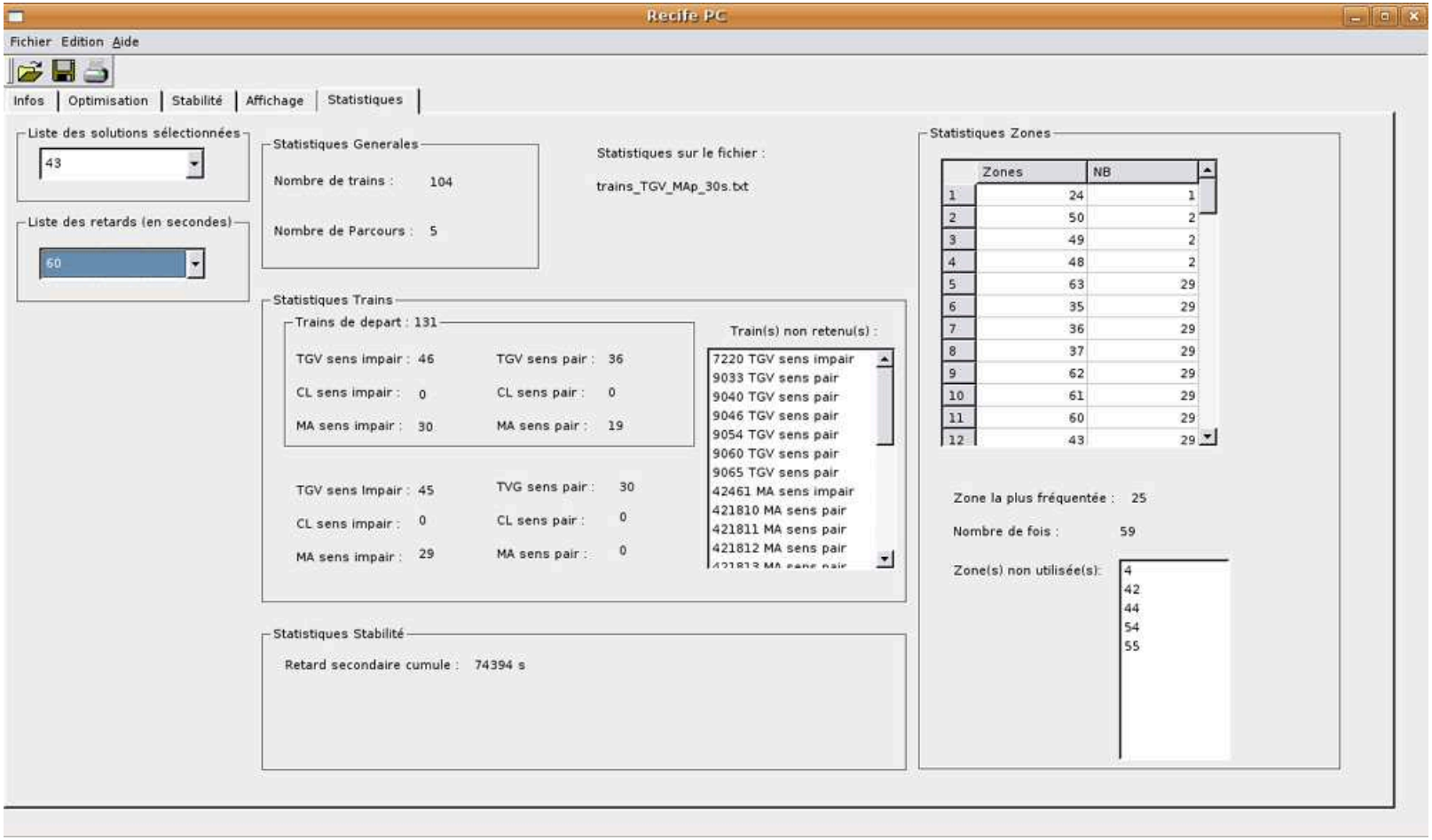
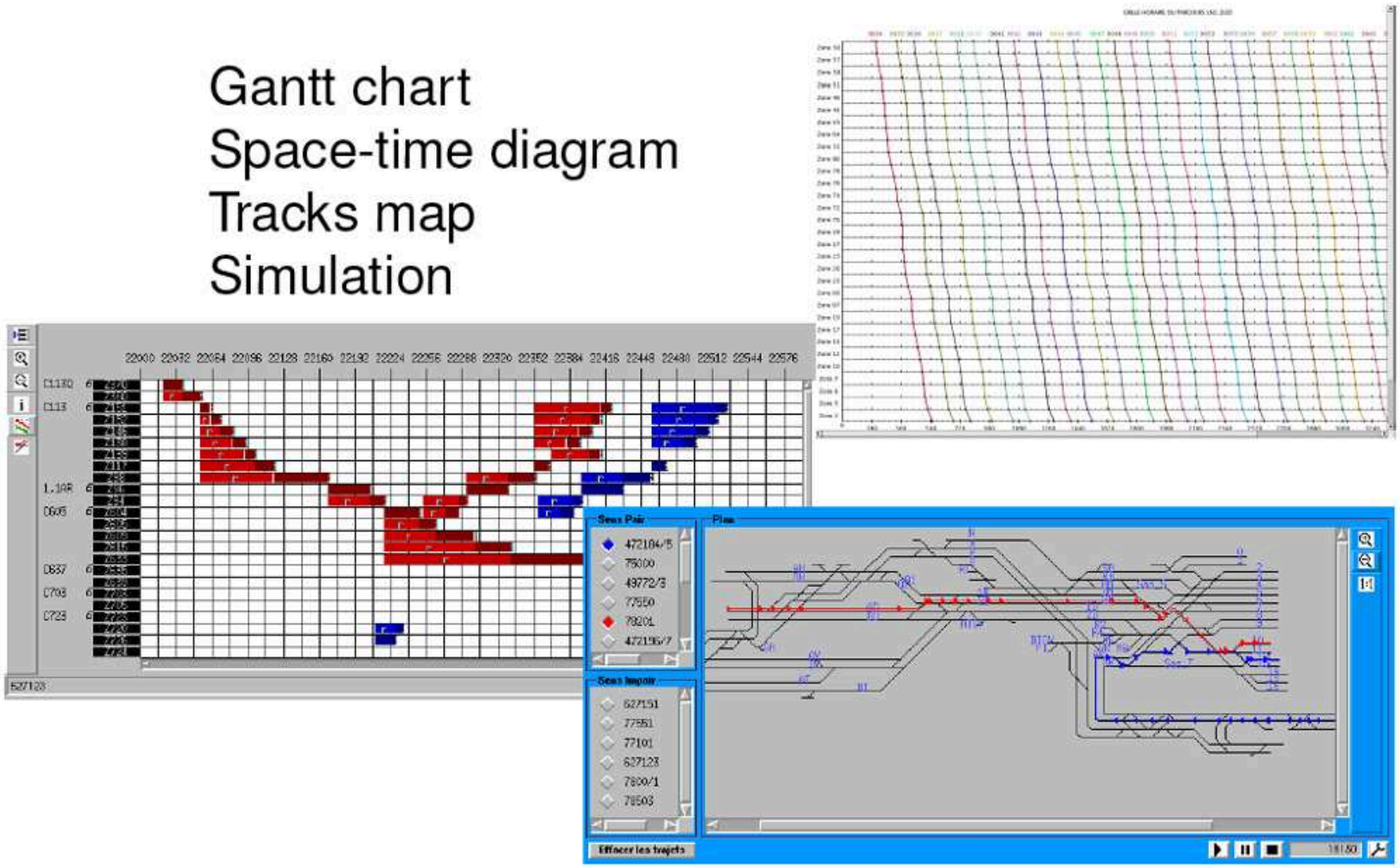


3.2 Screenshots: focussed on the core of the trade

Gantt chart
Space-time diagram
Tracks map
Simulation



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4. Conclusion

- An **optimization model** for feasibility and/or saturation
  - set packing problem
  - ant colony optimization based algorithm
  - list of equivalent (but different) railway timetables
- A **multiobjective model** for stability evaluation
  - delay propagation method
  - shortest path computation
  - multi-criteria analysis
- Both integrated in an **information system** for railway capacity evaluation of junction or station
- Future research works: **multiobjective optimization**:
  - search for compromises between capacity use and stability
  - preferences on the traffic integrated in the timetables

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