

RECIFE: a MCDSS for Railway Capacity

Xavier GANDIBLEUX⁽¹⁾, Pierre RITEAU⁽¹⁾, and Xavier DELORME⁽²⁾



(1) LINA - Laboratoire d'Informatique de Nantes Atlantique
Université de Nantes
2 rue de la Houssinière BP92208, F-44322 Nantes cedex 03 – FRANCE
Xavier.Gandibleux@univ-nantes.fr, Pierre.Riteau@etu.univ-nantes.fr



(2) Centre Génie Industriel et Informatique
Ecole des Mines de Saint-Etienne
158 cours Fauriel, F-42023 Saint-Etienne cedex 2 – FRANCE
Delorme@emse.fr

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Objectives of RECIFE project

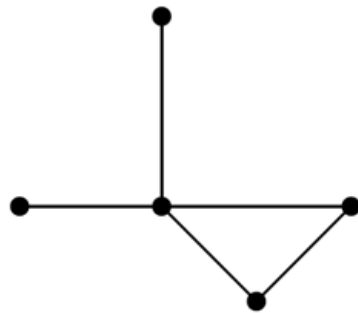
Research project with INRETS and SNCF:

- 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**

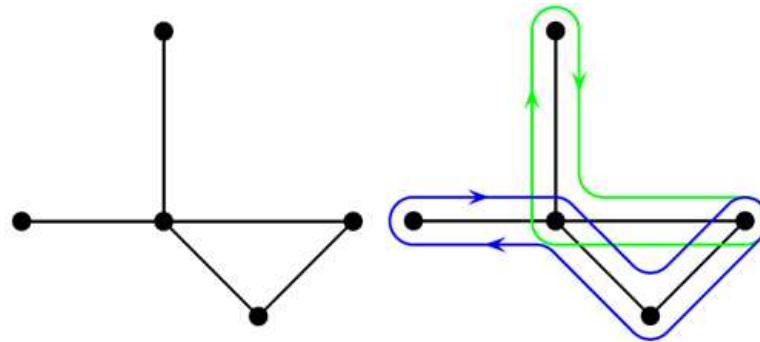
1.1 Problematic: a railway planning problem (RPP)

- Planning the construction or reconstruction of infrastructures



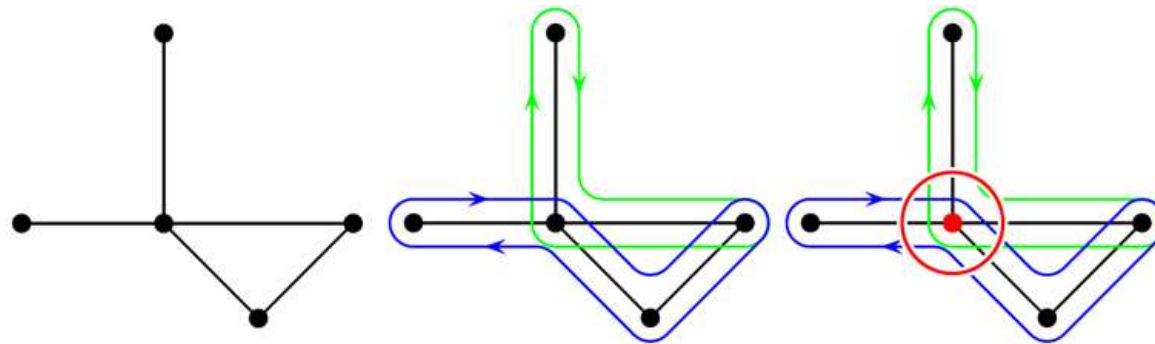
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- Planning the construction or reconstruction of infrastructures



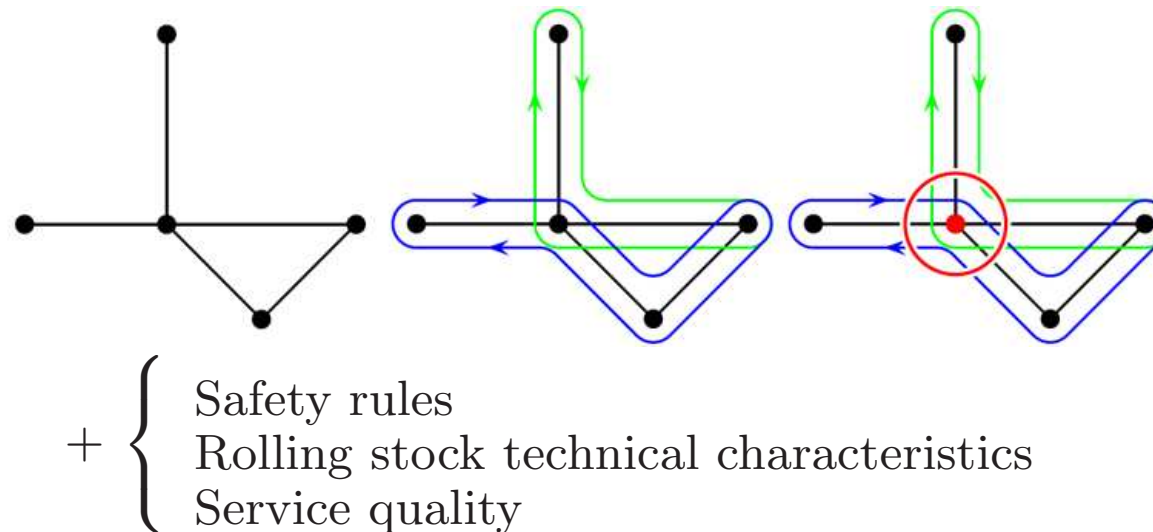
1.1 Problematic: a railway planning problem (RPP)

- Planning the construction or reconstruction of infrastructures



1.1 Problematic: a railway planning problem (RPP)

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

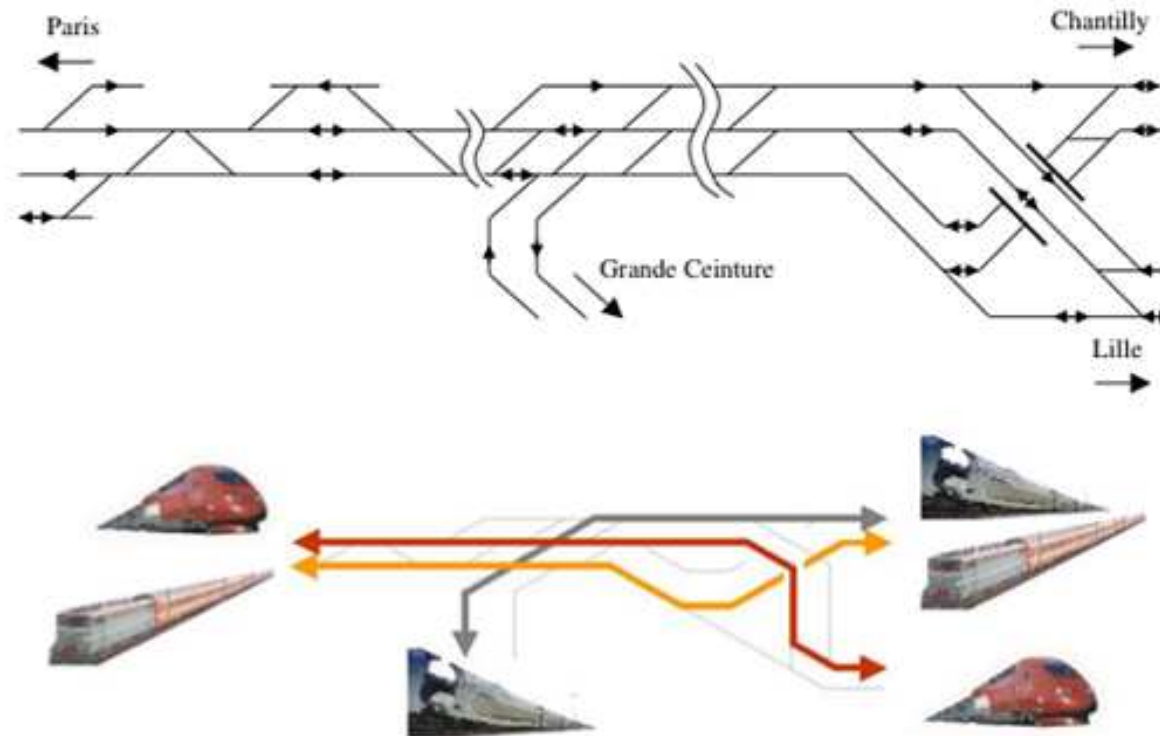


**How many trains can be routed
through the junction within a time interval?**

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

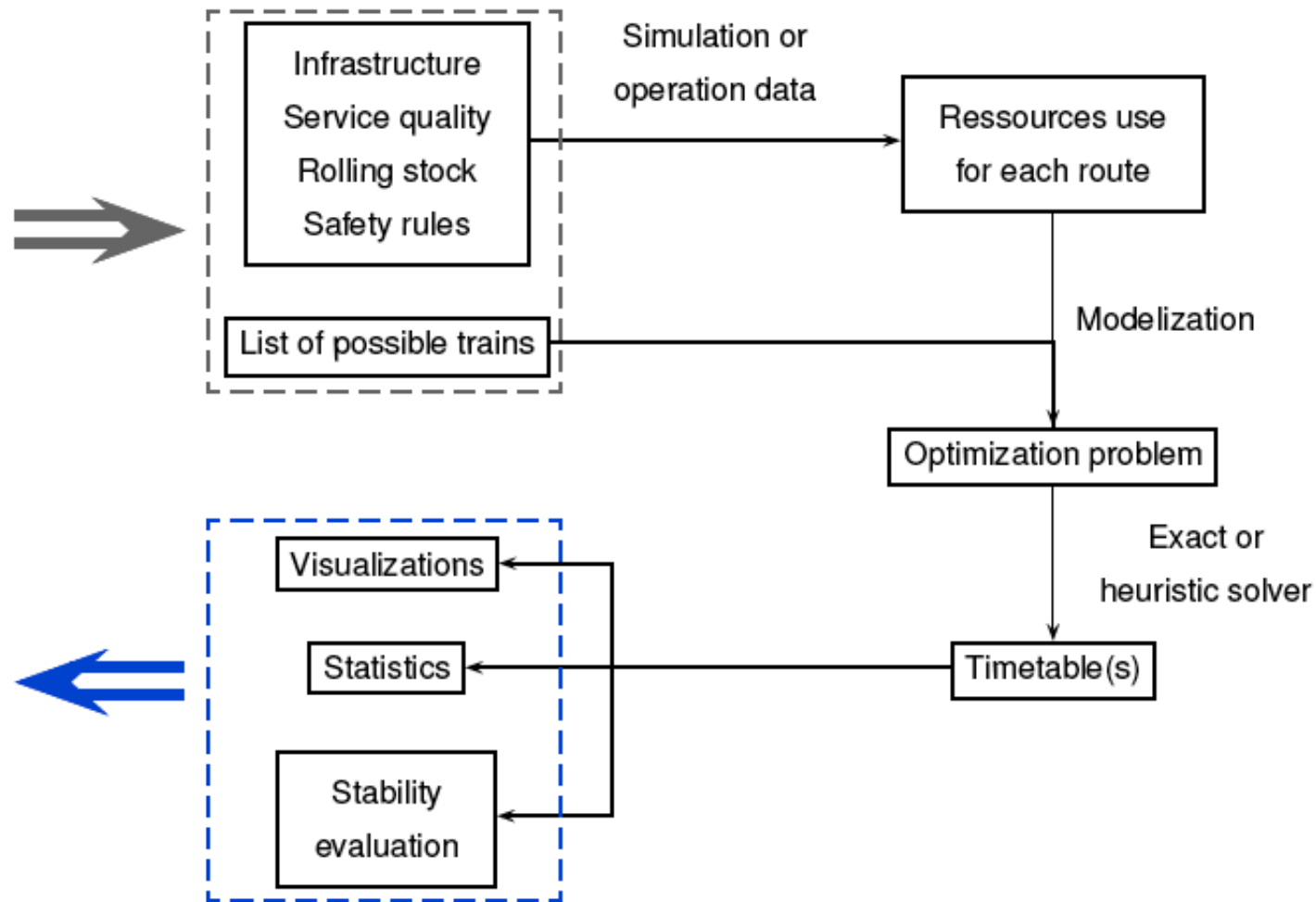


1.2 Decision process

- 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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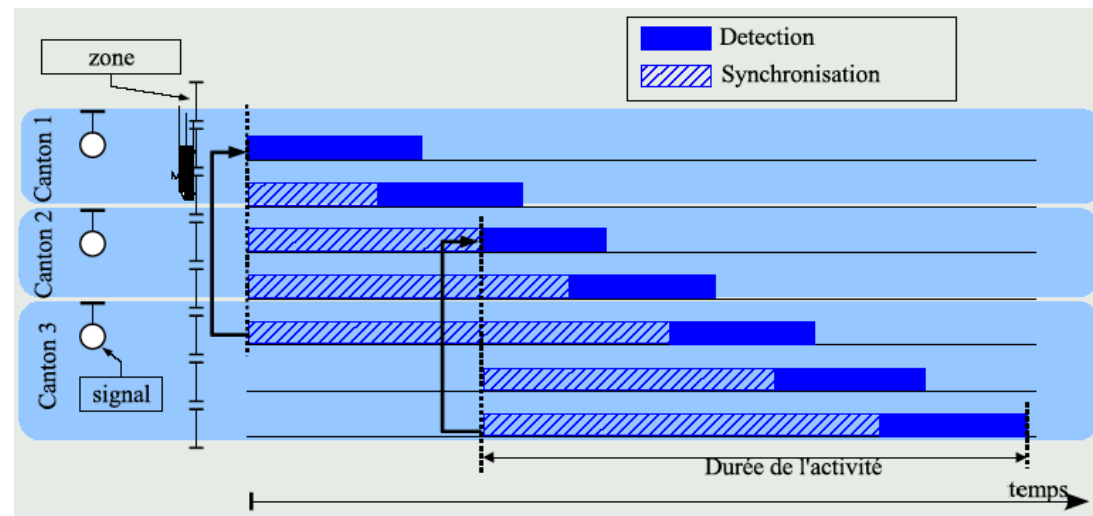
2.1 Organisation of the information system



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 consumed:



- One list of trains

2.2 Input data: one situation

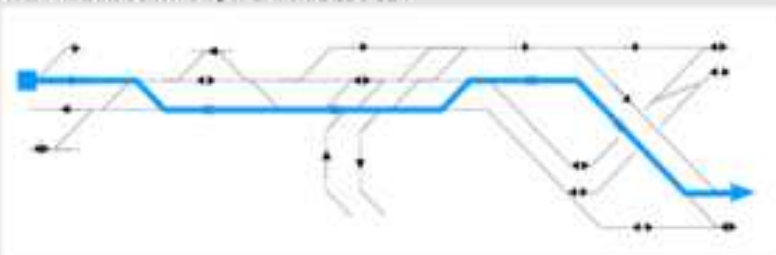
Fichier Train

Fichier de données des trains :

Trains : 7177, 7178, 7179, 7180, 7181, 7182, 7183, **7184**, 7185, 7186, 7187, 7188, 7189, 7190, 7191, 7192, 7193, 7194, 7195

Parcours : D2DC1LN, D2DD1LN, D2DE1LN, D2DF1LN, DC_M1LN, DC1D1LN, LN2_D2D, LN2MA2D, LN2MB2D, LN2MC2D, LN2MD2D, DC_MA1D, DC_MB1D, DC_ME1D, DC_MF1D, DC_MH1D, DC_MJ1D, DC_ML1D, DC1D1D

Train : Visualisation du parcours : D2DD1LN



Train : Zones du parcours : D2DD1LN

Número Zone : 1	Heure debut : 0	Heure Fin : 10
Número Zone : 3	Heure debut : 0	Heure Fin : 39
Número Zone : 8	Heure debut : 0	Heure Fin : 62
Número Zone : 9	Heure debut : 0	Heure Fin : 65
Número Zone : 7	Heure debut : 0	Heure Fin : 73
Número Zone : 10	Heure debut : 0	Heure Fin : 88
Número Zone : 12	Heure debut : 33	Heure Fin : 106
Número Zone : 13	Heure debut : 33	Heure Fin : 121
Número Zone : 17	Heure debut : 81	Heure Fin : 139

Informations du train sélectionné :

Nom : 7184 Liste des parcours : D2DC1LN, **D2DD1LN**, D2DE1LN, D2DF1LN, DC_M1LN, DC1D1LN

Type Train : TGV sens impair

Trains : 131

TGV sens impair : 46	TGV sens pair : 36
CL sens impair : 0	CL sens pair : 0
MA sens impair : 30	MA sens pair : 19

2.3 Handling the first criterion: optimization stage

Given

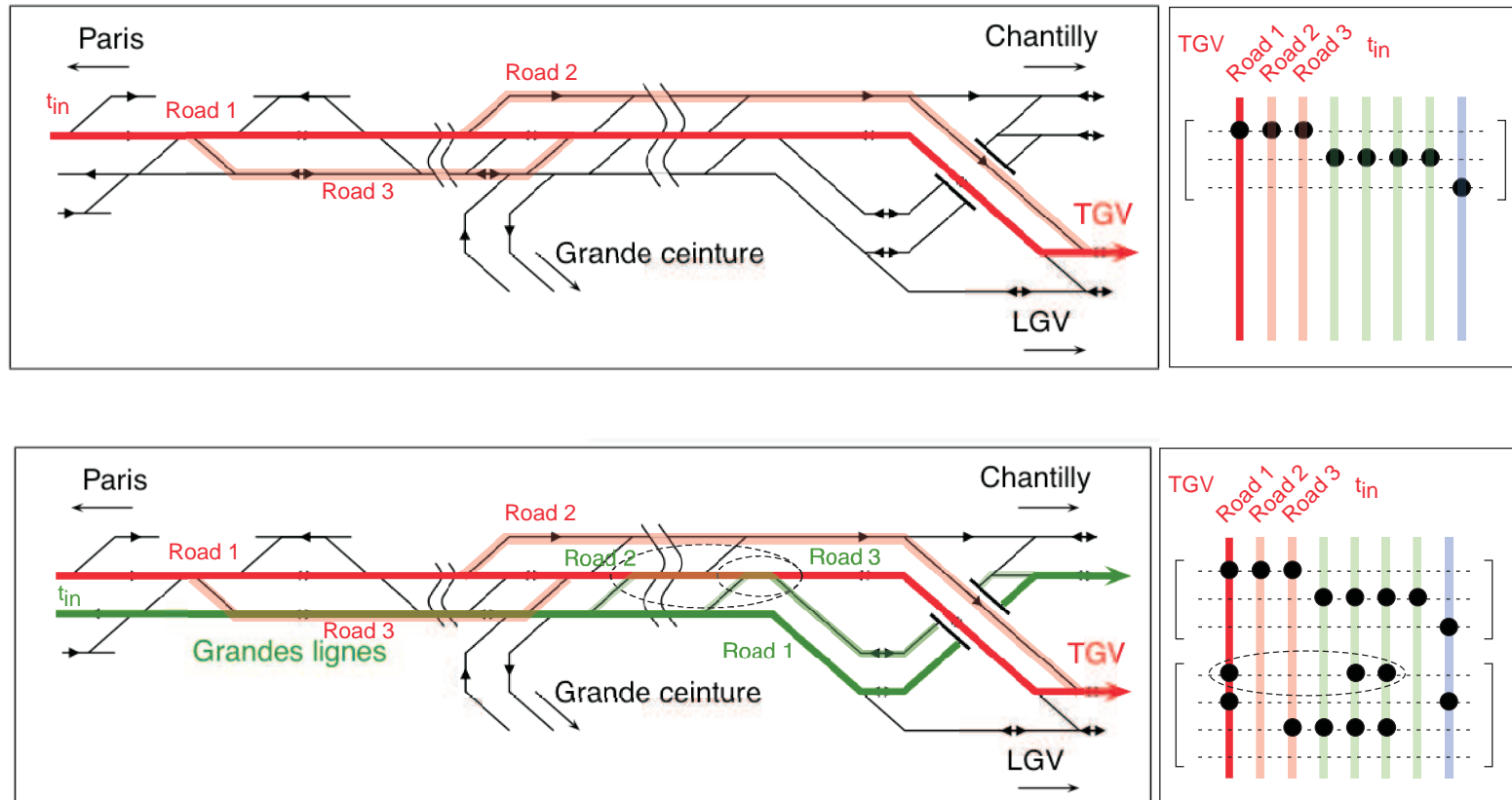
- a finite set $I = \{1, \dots, n\}$ of items
- $\{T_j\}, j \in J = \{1, \dots, m\}$, a collection of m subsets of I

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

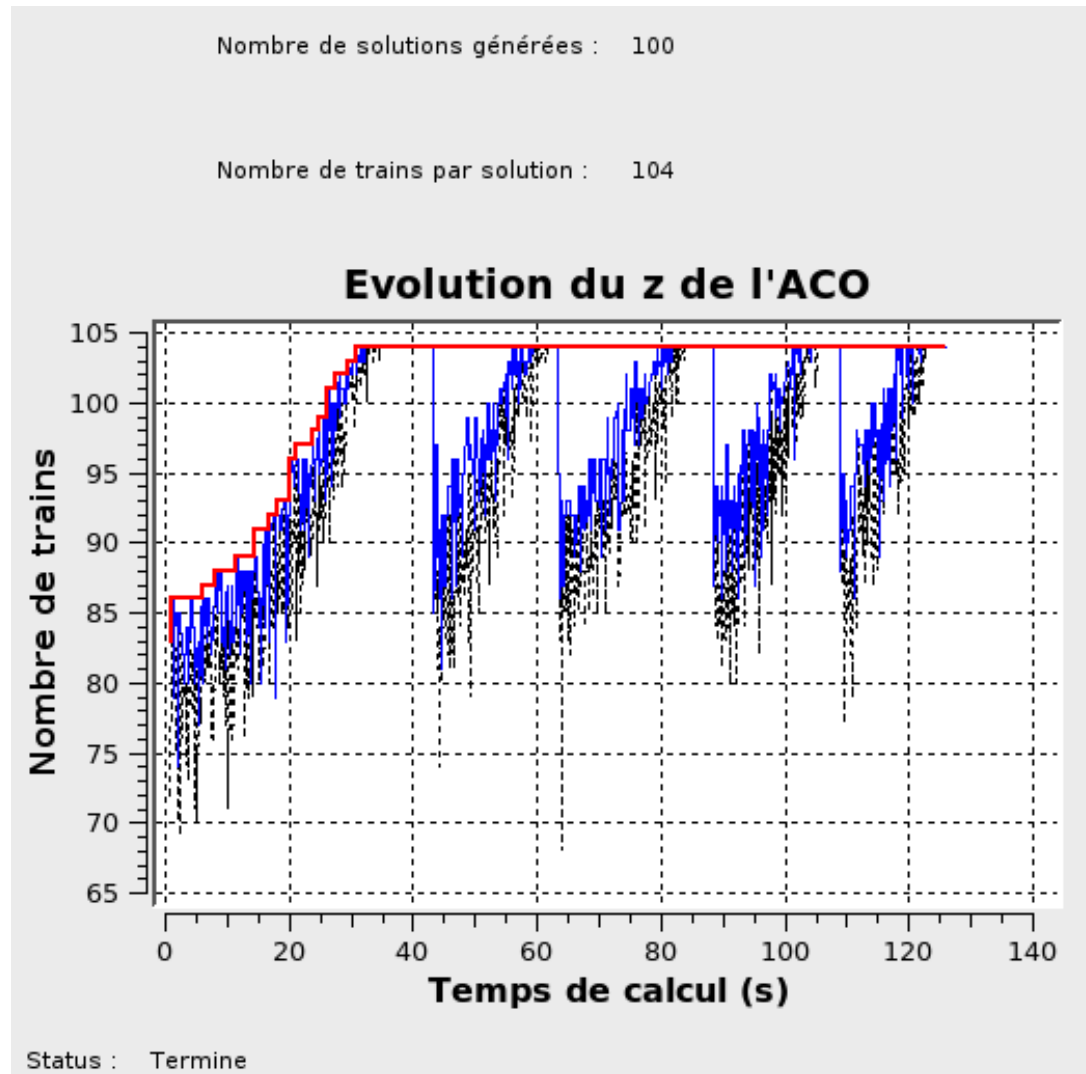
$$\left[\begin{array}{l} \text{Max } z(x) = \sum_{i \in I} c_i x_i \\ \sum_{i \in I} t_{i,j} x_i \leq 1, \forall j \in J \\ x_i \in \{0, 1\} \quad , \forall i \in I \\ t_{i,j} \in \{0, 1\} \quad , \forall i \in I, \forall j \in J \end{array} \right] \quad (SPP)$$

- 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



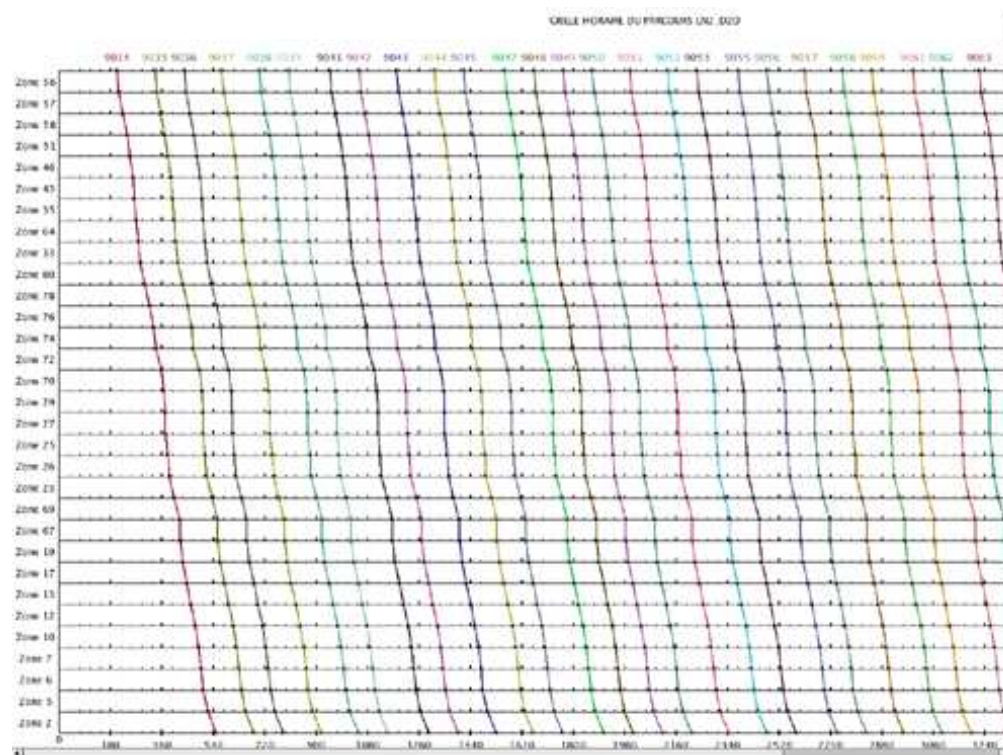
2.3 Handling the first criterion: optimization stage



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)

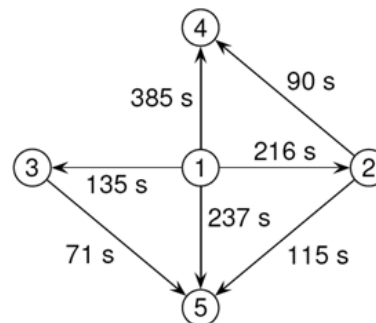
2.5 Handling the second criterion: simulation stage

Principle (2/2): delay propagation

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

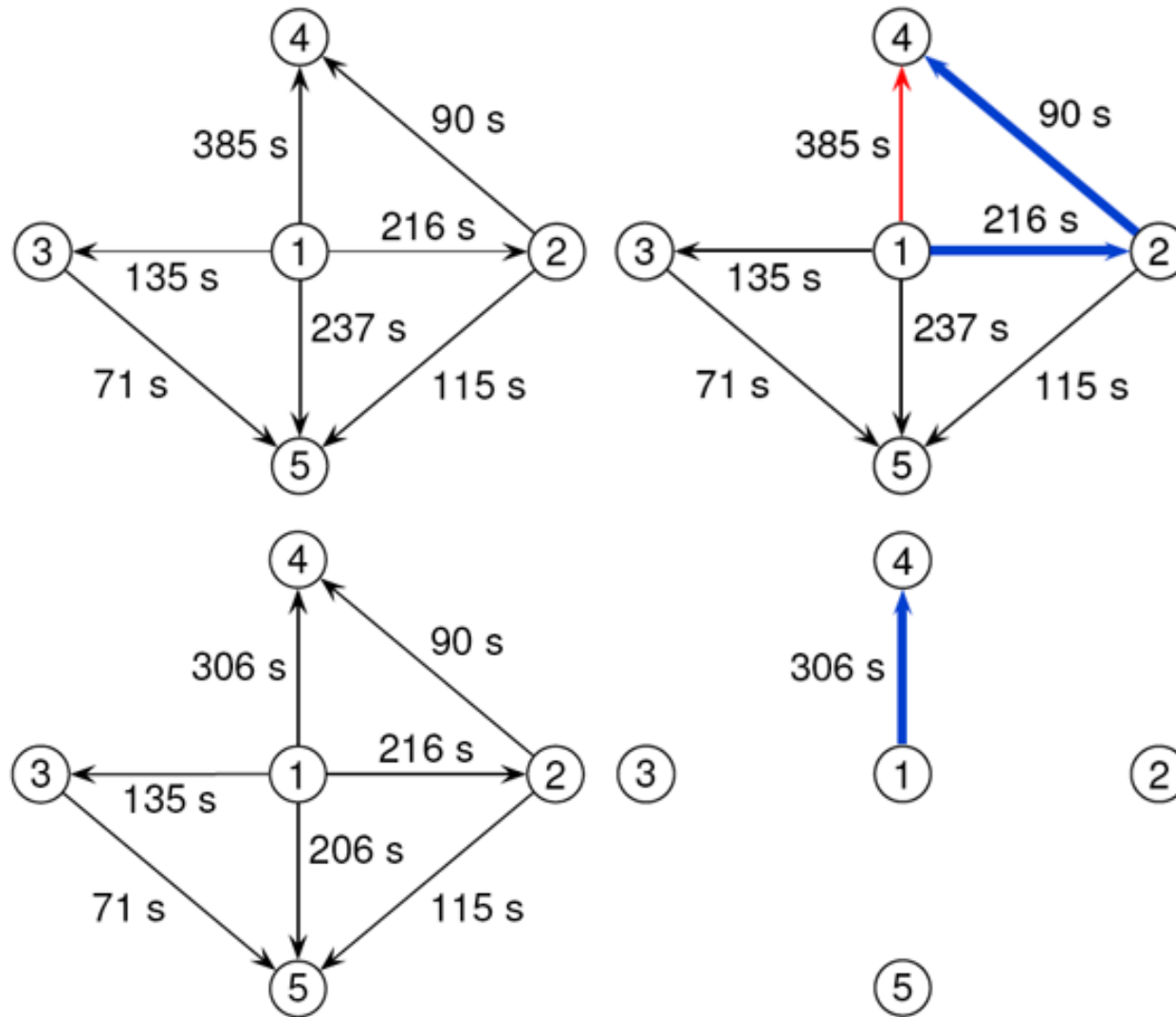
Illustration: didactic example on Pierrefitte-Gonesse node:

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

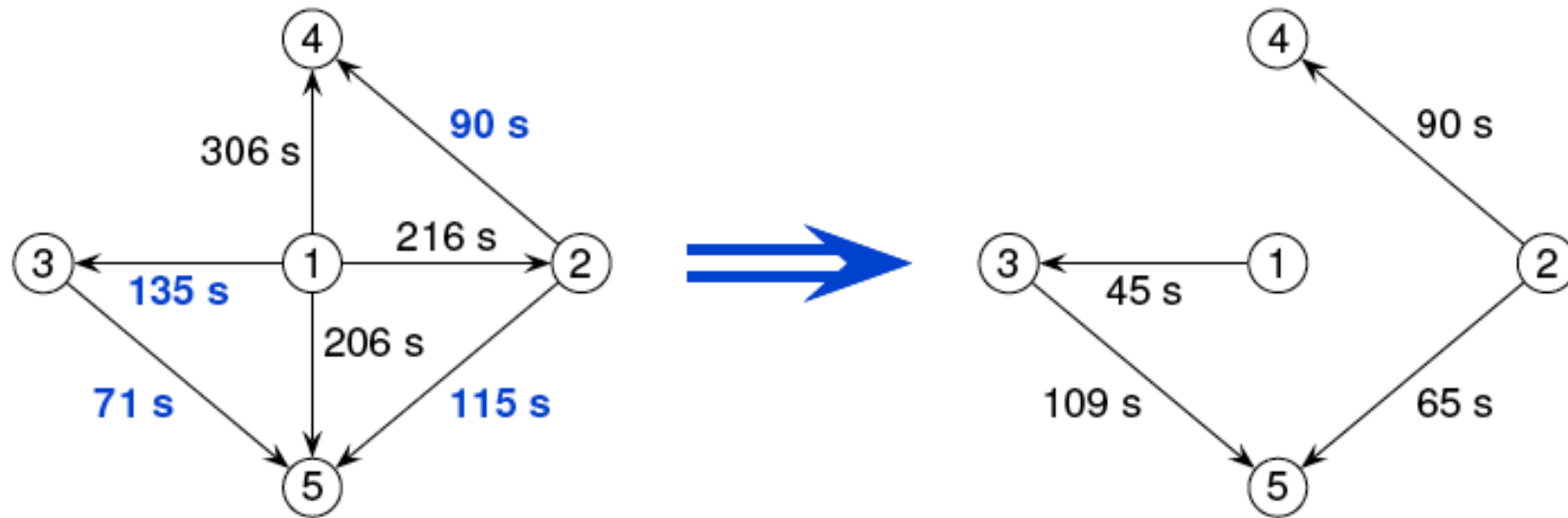


- 2 primary delay values (180s & 300s). For the primary delay of 180s:

2.5 Handling the second criterion: simulation stage



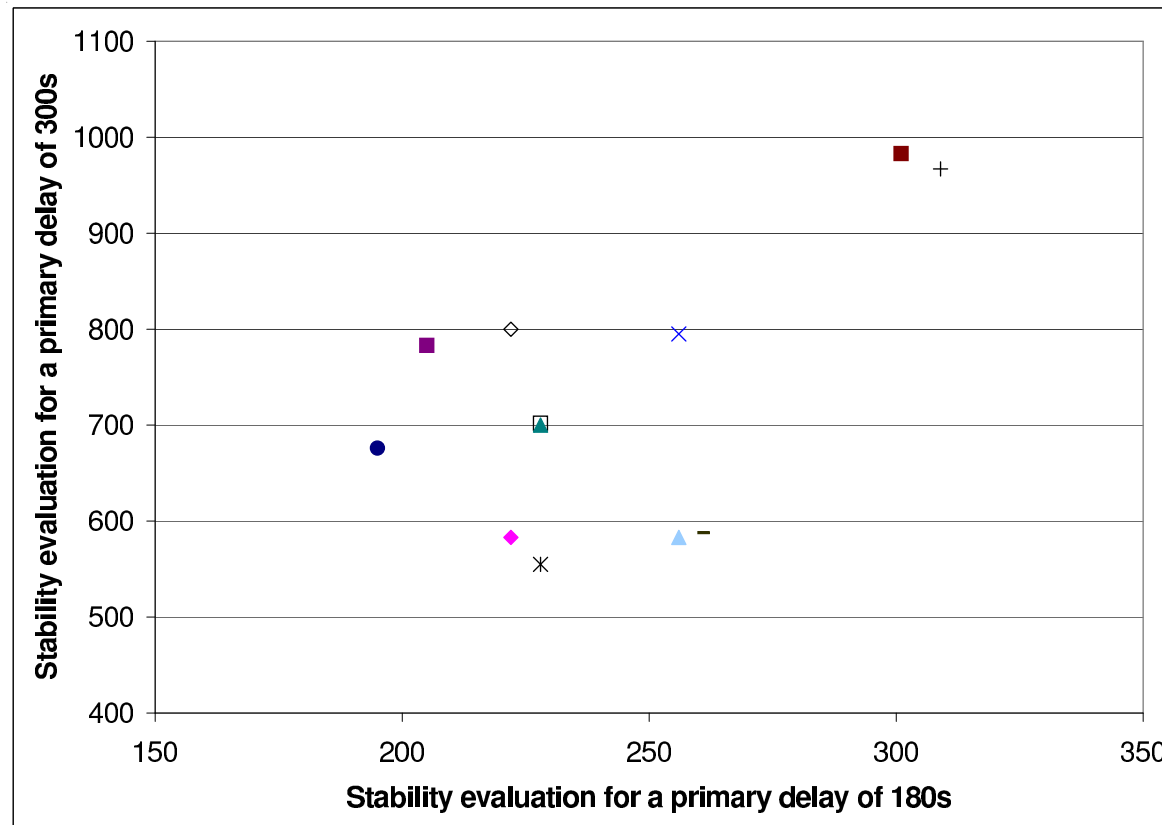
2.5 Handling the second criterion: simulation stage



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	:	<u>0 s</u>
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 \approx 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**
 - pairwise 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

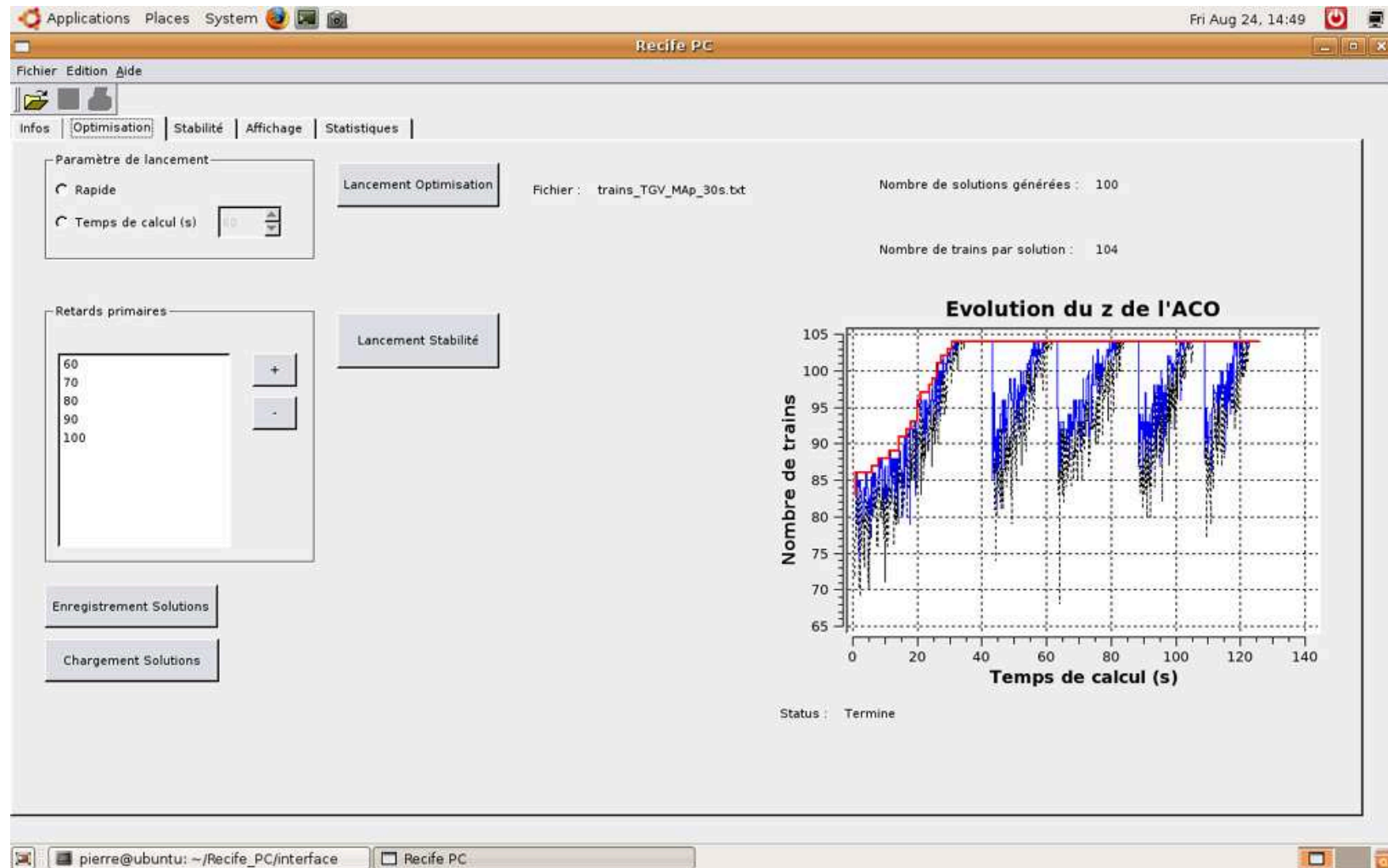
a solution is viewed inside the usual graphics handled by the DM (space-time graphic, gantt chart, simulation of traffic on the infrastructure)

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

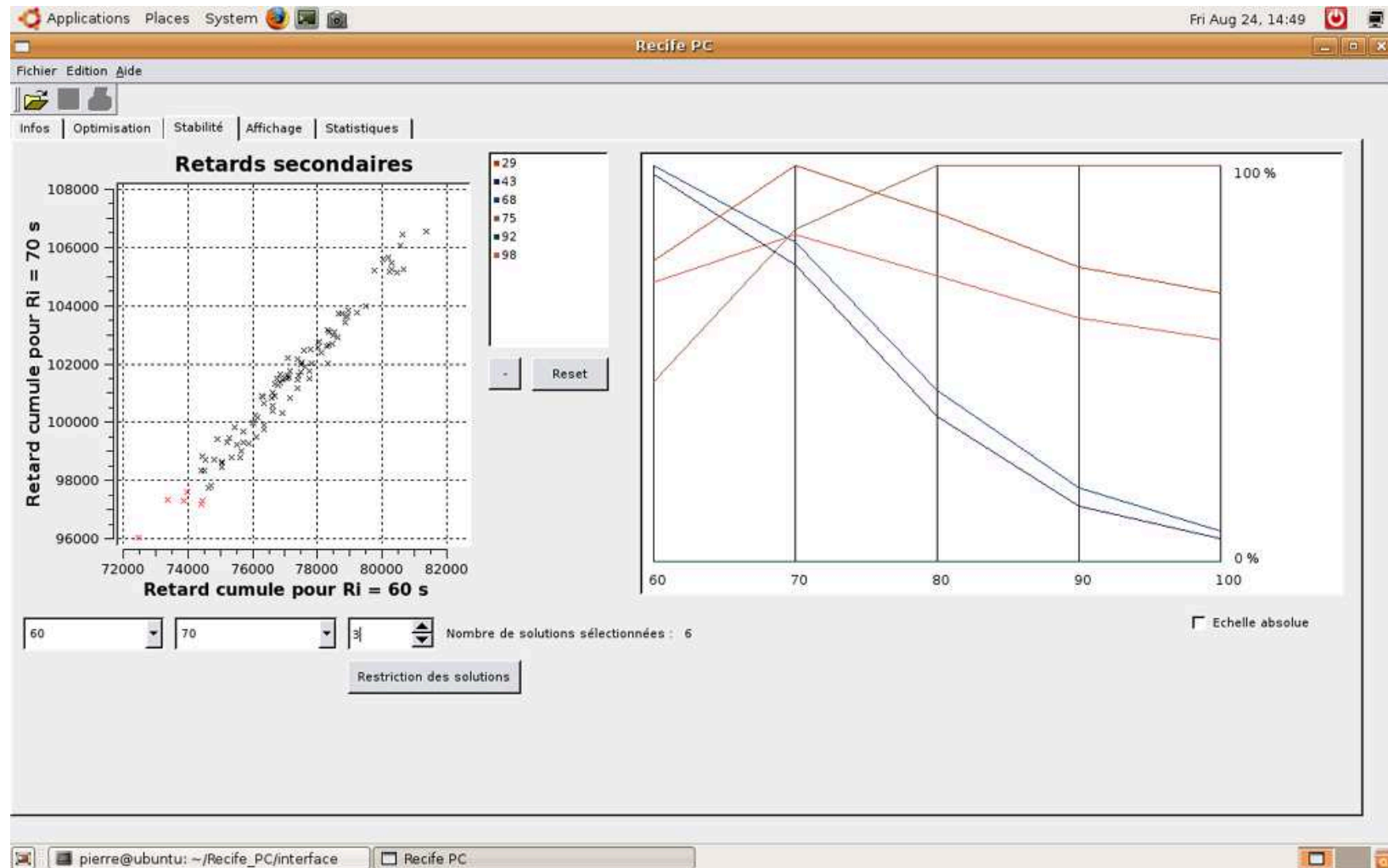
which maximizes the number of trains using the infrastructure,
for the given scenario of traffic,
with a good stability faced to possible delays

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3.1 Screenshots: focussed on the MCDM aspects



3.1 Screenshots: focussed on the MCDM aspects



3.2 Screenshots: focussed on a solution

Trains	Parcours	Heure d'entree	Retard maximum	Retard provoqué
1	7177 DC1D1LN	63000	0	272
2	9032 LN2MD2D	63000	40	299
3	42439 GCBSDMA	63000	0	519
4	7178 DC1D1LN	63080	59	219
5	42440 GCBSDMA	63122	59	484
6	7179 DC1D1LN	63160	59	165
7	9034 LN2_D2D	63204	16	856
8	7180 DC1D1LN	63240	59	110
9	42441 GCBSDMA	63244	59	408
10	9035 LN2_D2D	63336	35	1259
11	7181 DC1D1LN	63350	29	525
12	42442 GCBSDMA	63396	44	1514
13	7182 DC1D1LN	63430	59	495
14	9036 LN2_D2D	63438	59	466
15	7183 DC1D1LN	63510	59	465

Visualisation du parcours : DC1D1LN

Zones du parcours : DC1D1LN

- Numero Zone : 1 / Heure debut : 0 / Heure fin : 10
- Numero Zone : 3 / Heure debut : 0 / Heure fin : 39
- Numero Zone : 8 / Heure debut : 0 / Heure fin : 58
- Numero Zone : 9 / Heure debut : 0 / Heure fin : 66
- Numero Zone : 11 / Heure debut : 0 / Heure fin : 79
- Numero Zone : 14 / Heure debut : 33 / Heure fin : 86
- Numero Zone : 15 / Heure debut : 33 / Heure fin : 94
- Numero Zone : 16 / Heure debut : 33 / Heure fin : 109
- Numero Zone : 18 / Heure debut : 73 / Heure fin : 123
- Numero Zone : 20 / Heure debut : 73 / Heure fin : 130

3.2 Screenshots: focussed on a solution

The screenshot displays the 'Recife PC' application window with the following components:

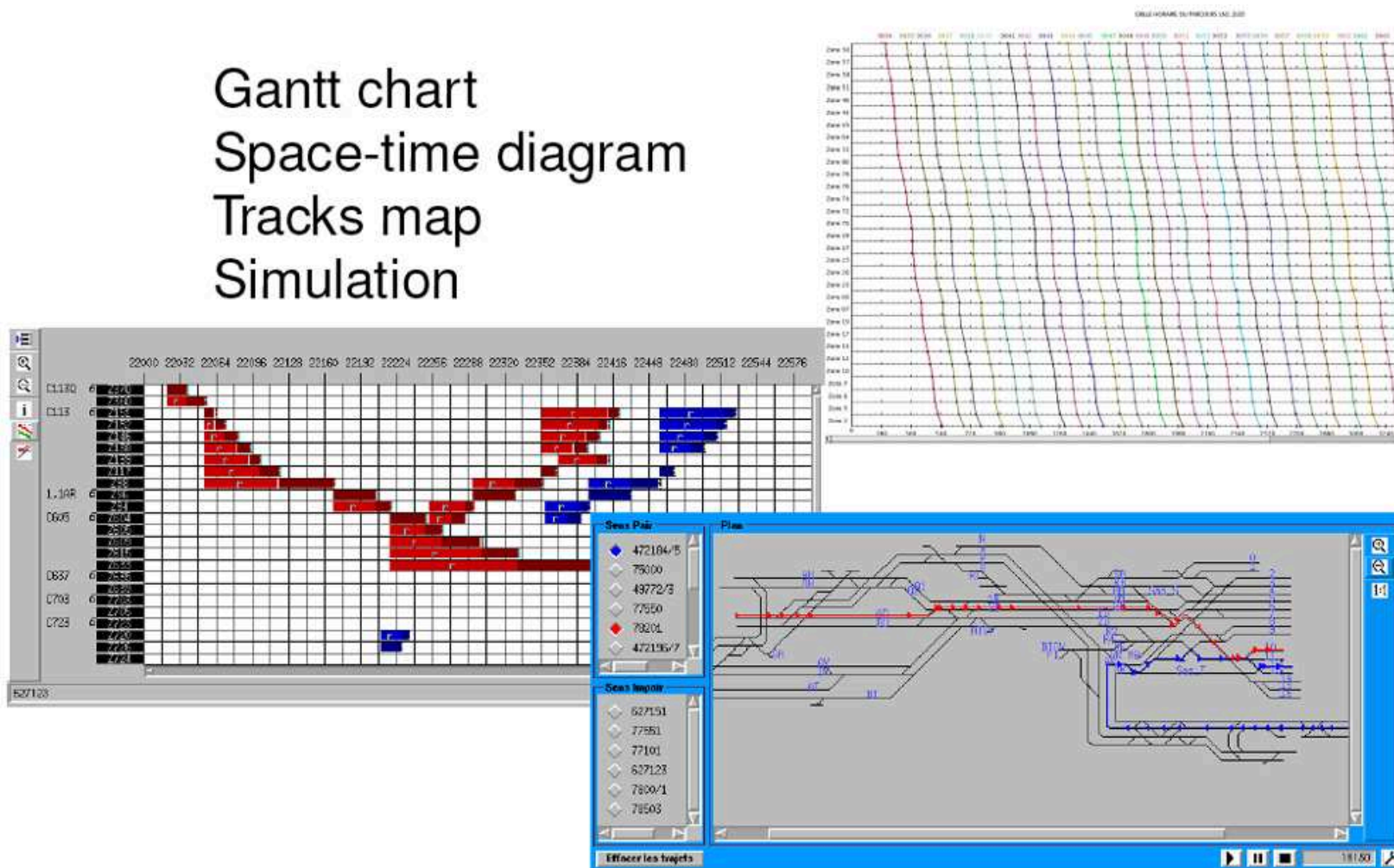
- Menu Bar:** Fichier, Edition, Aide
- Toolbar:** Icons for file operations and help.
- Navigation Tabs:** Infos, Optimisation, Stabilité, Affichage, Statistiques
- Left Panel:**
 - Liste des solutions sélectionnées: 43
 - Liste des retards (en secondes): 60
- Statistiques Generales:**
 - Nombre de trains : 104
 - Nombre de Parcours : 5
- Statistiques Trains:**
 - Trains de depart : 131
 - TGV sens impair : 46, TGV sens pair : 36
 - CL sens impair : 0, CL sens pair : 0
 - MA sens impair : 30, MA sens pair : 19
 - TGV sens Impair : 45, TVG sens pair : 30
 - CL sens impair : 0, CL sens pair : 0
 - MA sens impair : 29, MA sens pair : 0
- Statistiques sur le fichier:** trains_TGV_Map_30s.txt
- Statistiques Zones:**

Zones	NB	
1	24	1
2	50	2
3	49	2
4	48	2
5	63	29
6	35	29
7	36	29
8	37	29
9	62	29
10	61	29
11	60	29
12	43	29

 - Zone la plus fréquentée : 25
 - Nombre de fois : 59
 - Zone(s) non utilisées(s): 4, 42, 44, 54, 55
- Statistiques Stabilité:** Retard secondaire cumule : 74394 s
- Train(s) non retenus(s):**
 - 7220 TGV sens impair
 - 9033 TGV sens pair
 - 9040 TGV sens pair
 - 9046 TGV sens pair
 - 9054 TGV sens pair
 - 9060 TGV sens pair
 - 9065 TGV sens pair
 - 42461 MA sens impair
 - 421810 MA sens pair
 - 421811 MA sens pair
 - 421812 MA sens pair
 - 421813 MA sens pair

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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X. Gandibleux, X. Delorme, and V. T'Kindt. An ant colony algorithm for the set packing problem. In M. Dorigo, M. Birattari, Ch. Blum, L. Gambardella, Fr. Mondada, and Th. Stutzle, eds, *Ant Colony Optimization and Swarm Intelligence*, LNCS 3172, pp. 49–60. Springer, 2004.

X. Delorme, X. Gandibleux, and J. Rodriguez. Stability evaluation of a railway timetable at station level. *European Journal of Operational Research*, 2007. (Available online, doi:10.1016/j.ejor.2007.06.062).

J. Rodriguez, X. Delorme, X. Gandibleux, Gr. Marlière, R. Bartusiak, F. Degoutin, and S. Sobieraj. RECIFE: models and tools for analyzing rail capacity. *Recherche Transports Sécurité*, 95:19–36, 2007. (doi:3166/rts.95.19-36).