RECIPE: 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
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- 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
  \[
  \begin{align*}
  &\text{o the feasibility and/or saturation problem} \\
  &\text{plus} \\
  &\text{o the stability problem (ability to absorb delays)}
  \end{align*}
  \]

- Decision process structured lexicographically by two criteria:
  - 1st criterion:
    \text{max the number of train}
  - 2nd criterion:
    \text{max the stability among the equivalent timetables (minimize the sum of delays)}
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2.1 Organisation of the information system

Simulation or operation data → Ressources use for each route → Modelization → Optimization problem → Exact or heuristic solver → Timetable(s)

List of possible trains → Infrastructure
Service quality
Rolling stock
Safety rules

Visualizations
Statistics
Stability evaluation
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
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

\[
\begin{align*}
\text{Max } z(x) &= \sum_{i \in I} c_i x_i \\
\sum_{i \in I} t_{i,j} x_i &\leq 1, \forall j \in J \\
x_i &\in \{0, 1\}, \forall i \in I \\
t_{i,j} &\in \{0, 1\}, \forall i \in I, \forall j \in J
\end{align*}
\]

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

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2.3 Handling the first criterion: optimization stage

[Diagram showing traffic flow and road networks with labels such as Paris, Chantilly, and TGV.]
2.3 Handling the first criterion: optimization stage

Nombre de solutions générées : 100

Nombre de trains par solution : 104

Evolution du z de l’ACO

Status : Termine
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:

  ![Diagram](image.png)

  - 2 primary delay values (180s & 300s). For the primary delay of 180s:
2.5 Handling the second criterion: simulation stage
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![Diagram showing train delays and stability evaluation]

- 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**

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2.5 Handling the second criterion: simulation stage

Representation in the outcome space

12 timetables ⇒ 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 comparison (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
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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
1. Railway Infrastructure Operation Planning

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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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