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Paola Pellegrini

RECIFE: an advanced platform for the design and test of railway traffic management optimization

Université Gustave Eiffel

Context

Currently, little optimization is deployed **in practice** in railway planning and management processes

However, the **willingness** of infrastructure managers to move toward it is clearly increasing

Academic researchers have been working for many years to make optimized traffic management **possible**

Context

In this context,
the traffic management team of the COSYS-ESTAS laboratory of Université Gustave Eiffel
has been working on the
RECIFE platform
for more than 20 years

RECIFE deals on railway traffic management, **broadly speaking**

This presentation focuses on **real-time traffic management**

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Real-time traffic management

It aims at **minimizing the impact** of perturbations

It comes at the end of a long traffic management and planning **process** (including infrastructure design, line planning, timetabling, ...)

The railway system [1] has some characteristics that make traffic management **critical and complex**, e.g. :

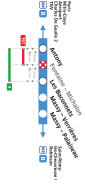
- timetables can be extremely dense
- mixed traffic often share common tracks (freight, conventional passenger, high speed trains)
- railway is invested of a high economic and societal responsibility, to allow sustainable mobility and accessibility

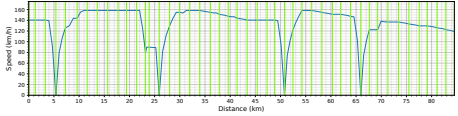
1. In Europe, but not only

Deciding traffic management measures to minimize the impact of perturbations

Various interpretations depending on : **Decisions**

routing, passing orders, departure times, speed profiles, stop patterns, ...

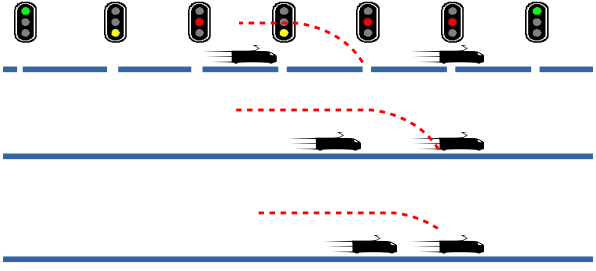




Deciding traffic management measures to minimize the impact of perturbations

Various interpretations depending on : **System**

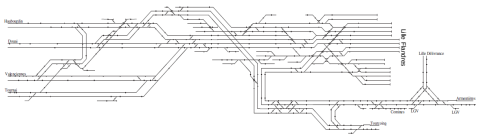
current, planned, envisaged, ...



Deciding traffic management measures to minimize the impact of perturbations

Various interpretations depending on : **Perimeter**

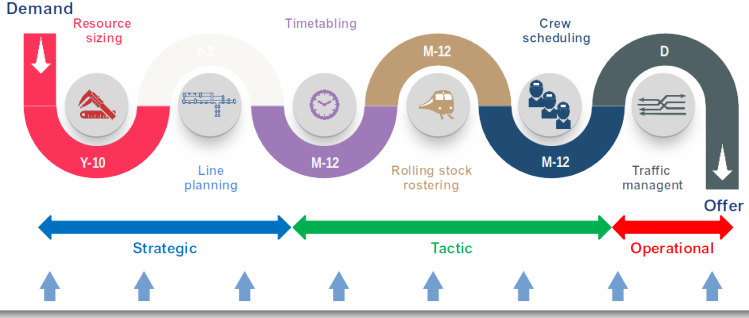
big station, network with many small stations, mixed traffic network, ..., urban service, high speed, mixed, ...

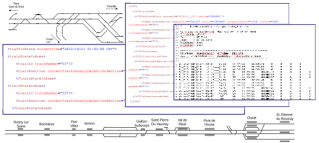


Deciding traffic management measures to minimize the impact of perturbations

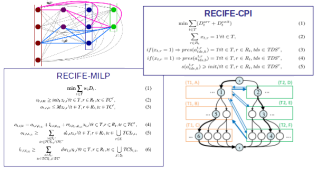
Various interpretations depending on : **Decision making**

only real-time traffic management, whole transport planning process, ...





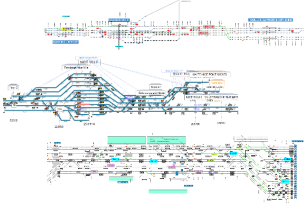
Case studies



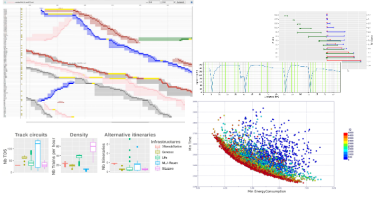
Models & Algorithms

RECIFE

Simulators



Tools & Interfaces



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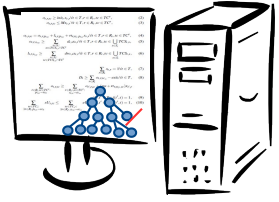
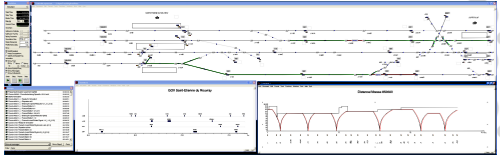
Peculiarities : integration of optimization and simulation

Optimization



and

Simulation



decision making
simplification hypotheses

application of predefined rules
fewer simplifications

Peculiarities : integration of optimization and simulation

Our studies often integrate **optimization and simulation**

Strength

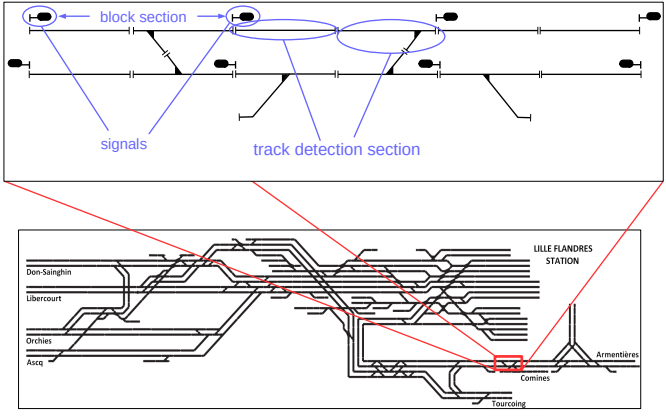
Analyses and conclusions are less dependent on modeling hypotheses

Challenge

Master concurrently optimization techniques, simulation tools, APIs

Deal with **technical issues** for integrating natively independent modules

Peculiarities : microscopic infrastructure model



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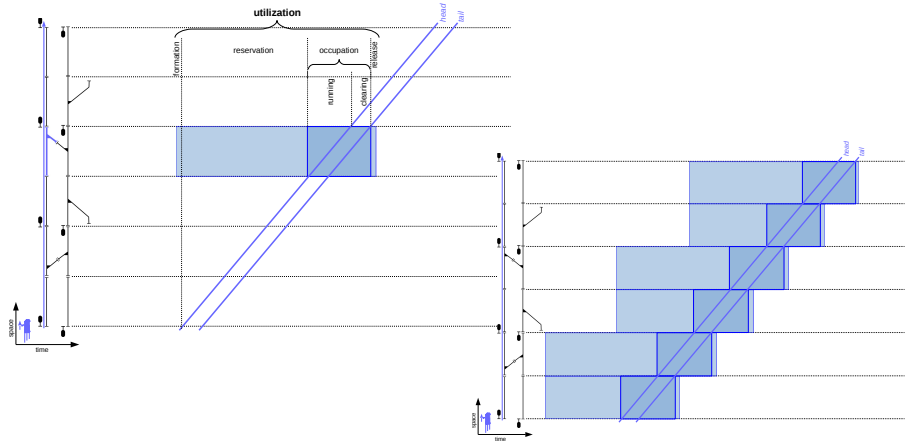
Peculiarities : microscopic infrastructure model



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Peculiarities : microscopic infrastructure model

Our models :

- use all information on **infrastructure topology and train capabilities**
- implement the **route-lock sectional-release interlocking** system

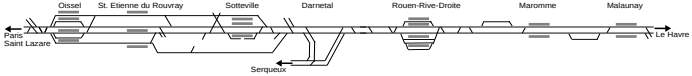
Strength

Full exploitation of infrastructure capacity

Challenge

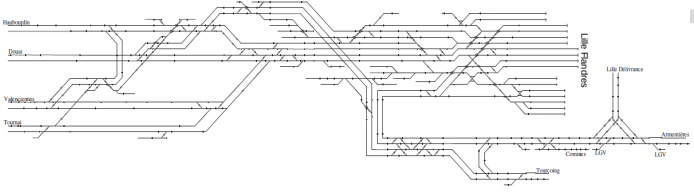
Effectively deal with big data sets

Peculiarities : exploitation of local rerouting



$\rightarrow$ up to $\sim$ 300 alternative routes

up to $\sim$ 450 $\leftarrow$ alternative routes



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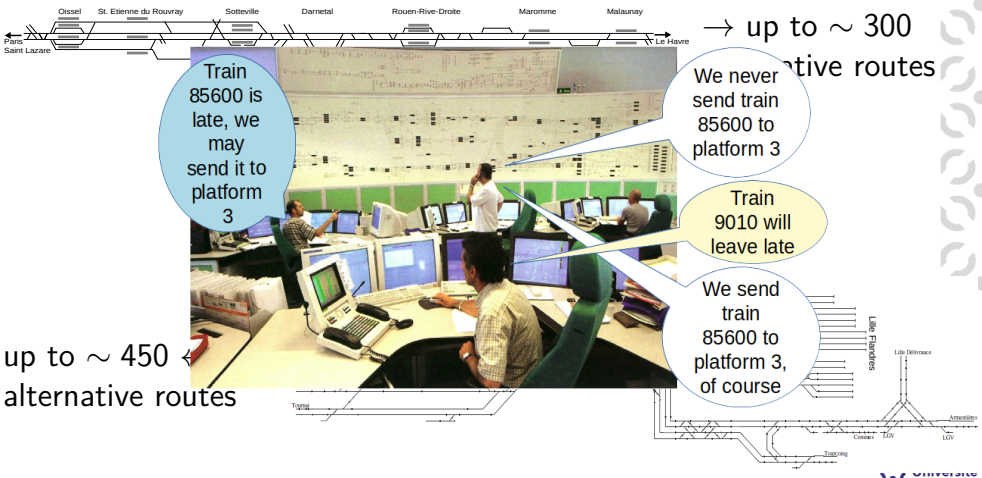
Peculiarities : exploitation of local rerouting



$\rightarrow$ up to $\sim$ 300 [illegible]ative routes

up to $\sim$ 450 [illegible]
alternative routes

Peculiarities : exploitation of local rerouting

Our models are meant to be able to deal with **large sets of alternative routes**

Strength

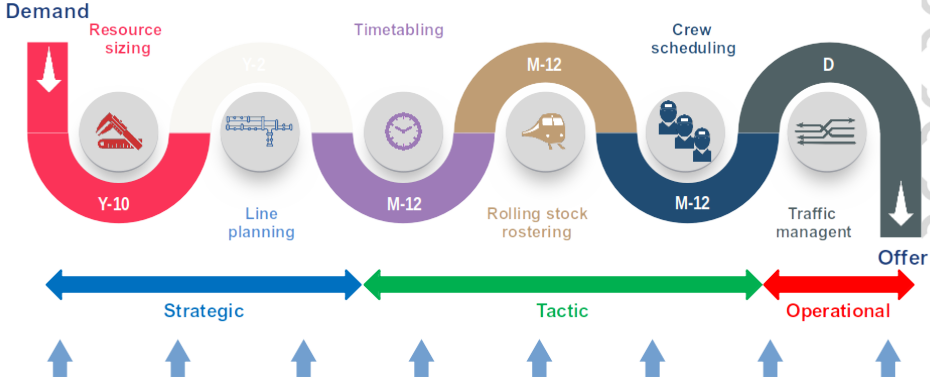
Full exploitation of infrastructure capacity

Challenge

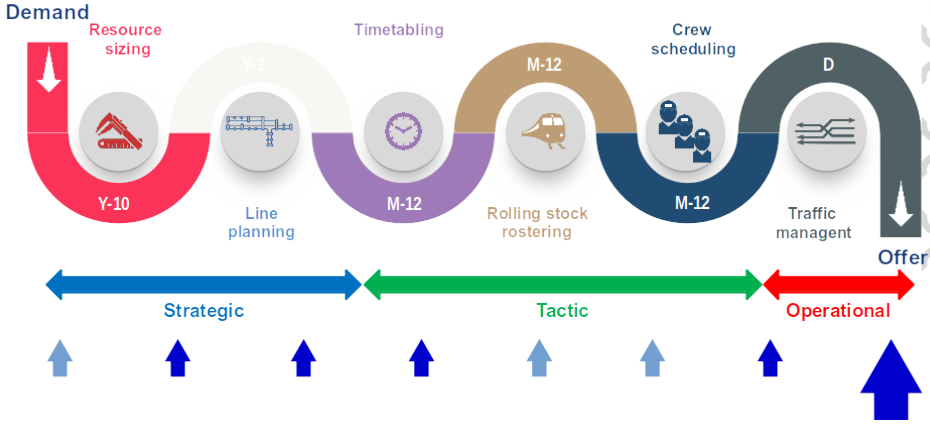
Effectively deal with large instances

Solve a routing and scheduling problem

Peculiarities : model consistency



Peculiarities : model consistency



Peculiarities : model consistency

Our models of different problems are designed to be **consistent**

Some problems are considered **jointly**

Strength

Decisions made in different stages are coherent

Lessons learned can be generalized, to some extent

Better solutions may exist for joined rather than sequential problems

Challenge

Understand what lessons learned can be **generalized**

Deal with increased **complexity** of problems tackled jointly

Success stories

In the years, we have used RECIFE for a number of **applications**

They have stimulated the **design and development** of advances

I consider many of them success stories

In the following, some **examples**

RECIFE-MILP

Mixed integer linear programming-based algorithm for routing & scheduling

It has been integrated with **simulators**, in open [2] and closed-loop [3]

It has achieved the **best results** in the benchmarking possible so far [2]

A variant is currently being used in the SORTEDmobility project : intelligent trains formulate traffic management hypotheses for self-organization

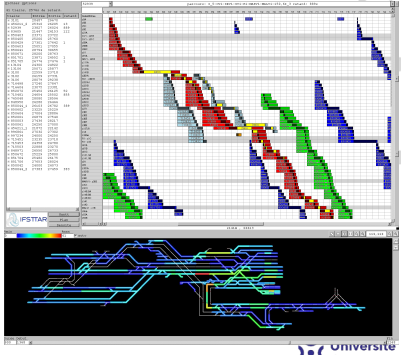
2. SIGIFRET project
3. ONTIME project

RECIFE-CP, RECIFE-CPI and hybridization

RECIFE-CP : **constraint programming** for train routing & scheduling

First studies with RECIFE in the early 2000 :

- optimization and simulation
- microscopic model
- specific focus on train rerouting
- variants for
  - real-time traffic management
  - timetabling
  - saturation problems



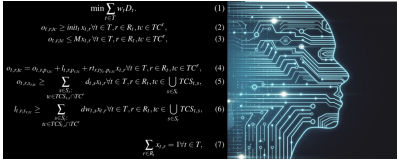
RECIFE-CP, RECIFE-CPI and hybridization

RECIFE-CP : **constraint programming** for train routing & scheduling

RECIFE-CPI : evolution of RECIFE-CP exploiting **time-interval variables**

Hybrid RECIFE-CPI & RECIFE-MILP : exploitation of

- MILP scheduling strength
- CPI ability to explore very large search spaces



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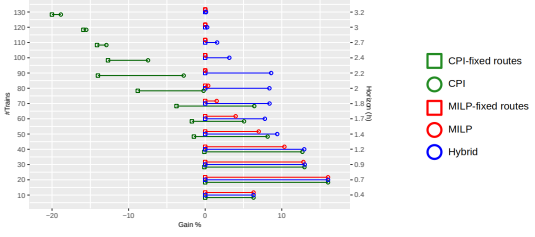
RECIFE-CP, RECIFE-CPI and hybridization

Hybrid RECIFE-CPI & RECIFE-MILP

Percentage improvement w.r.t. a reference solution

- Lille Flandres (e.g.)
- 3 min computation
- ↑ increasing # trains
- up to 3.5 h (130 trains)



- the more **on the right** the dot, the higher the improvement
- the **longer** the line, the larger the contribution of rerouting

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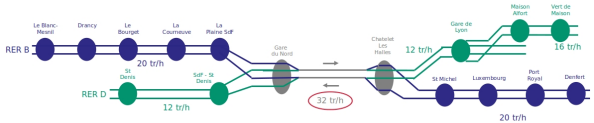
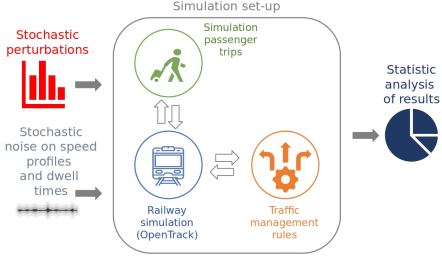
Traffic smoothing in Paris suburban network

Assessment in simulation (trains + passengers) of different rules [4]





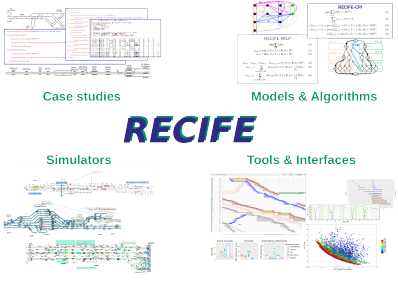
4. Study commissioned by SNCF Réseau

Conclusions

RECIFE : software platform to create and assess **tools for optimizing** railway traffic management problems

RECIFE main peculiarities :

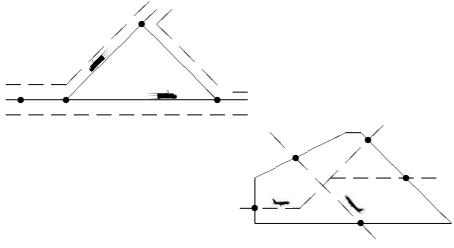
- optimization and simulation
- microscopic model
- local rerouting
- problem consistency



It allowed doing interesting things and allows thinking of many very interesting **new challenges** to take

Perspectives : improved traffic management quality

Exploit the constantly evolving **state of the art** in optimization and computer science



- new techniques
- cross-fertilization
- improved computing power
- ...

We need to carry on **improving** our algorithms and design **new** ones

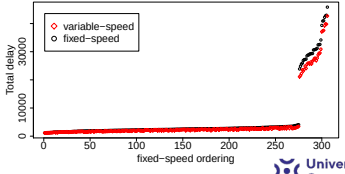
Perspectives : realistic models

Keep studying the ability of the models to **represent reality** :

- is a solution that appears good in the model actually good in reality ?
- are optimization decisions good despite the unavoidable imprecision of input data ?
- are we including all critical aspects of the problems ?
- what is the impact of omitting some aspects ?

We need to **answer** these questions

We need to try to improve the models **based on these answers**



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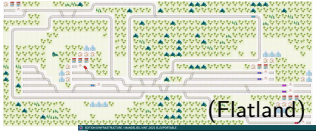
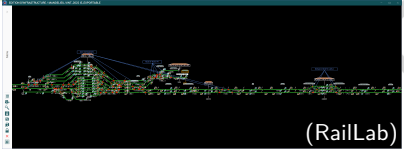
Perspectives : different simulators

Continue integrating and testing with different simulators, **not to be biased** by their modeling assumptions [5]

- Opentrack
- RailLab
- EGTrain
- Brave
- OSRD
- Flatland
- Trenissimo
- SimMobility
- ...


(Flatland)


(RailLab)

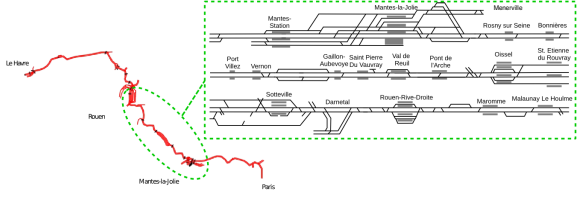
We need to **solve** the new technical issues arising

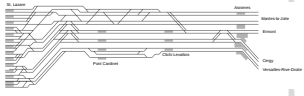
We need to find out how to **analyze** the difference in the results

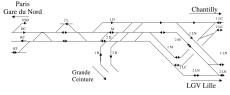
5. List in imprecise order, representing the current level of integration with RECIFE

Perspectives : many case studies

Keep increasing the panel of case studies for assessment,
to be able to generalize conclusions
and understand links case study /performance





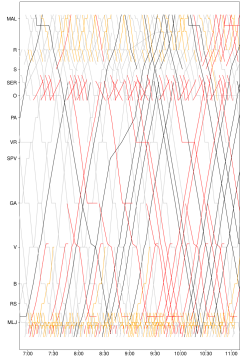


We need to struggle with **data collection, modeling and validation**

We need to find out how to **analyze** the difference in the results

Perspectives : various problems

Advance in the modeling and solution of problems emerging at different stages of the transport planning process



We need to design and study **pertinent models and algorithms**

We need to understand the **links** between problems

We need to devise **feedback loops** to exploit knowledge from all stages

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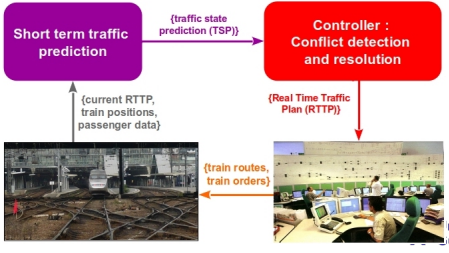
Perspectives : process design impact

Study how the design of traffic management processes impacts on how optimization needs, e.g. :

- human in the loop
- optimization triggers
- computational times
- actors involved
- ...

We need to understand the field **requirements and options**

We need to find out how optimization can and shall **fit** them



Thank you all for the attention, and for your questions and comments (now or later)

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Please contact me if you'd like to join the team in some way, or pass the message to brilliant master and PhD students you may know !

Special thanks to all RECIFE **designers and contributors** [6] :
Joaquin Rodriguez, Grégory Marlière, Sonia Sobieraj Richard, Paola Pellegrini, Diego Arenas Pimentel, Raffaele Pesenti, Pierre Hosteins, Marcella Samà, Teresa Montrone, Nicola Coviello, Kaba Keita, Franck Kamenga, Federico Naldini, Bianca Pascariu, Matteo Petris, Xiajie Yi, Bishal Sharma, Nina Versluis

6. Non-exhaustive list of Université Gustave Eiffel members (visiting or more), in more or less chronological order, since 2010

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