

# ROADEF/EURO 2014 Challenge

# Trains don't vanish!

Rolling stock unit management on railway sites

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# SNCF Group: main figures

- Historically, French national railways company
- Today one of the leading group of sustainable mobility worldwide



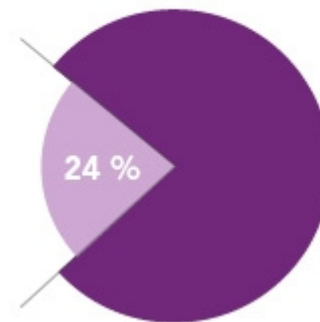
**250,000**

employees in 120 countries.

**€2.3 bn**

investment in 2012.

Revenue generated outside France.



**€33.8 bn**

revenue in 2012.



**4 million**

passengers a day take our trains.

# SNCF Group: 5 divisions



## SNCF INFRA

**Renovation & construction**  
Includes Sferis and Eurailscout

**Projects and engineering**  
Systra

**Rail traffic**  
Direction de la Circulation Ferroviaire (DCF<sup>(1)</sup>)



## SNCF PROXIMITÉS

**TER** (regional express transport by rail and road)

**Transilien** (rail transport for Greater Paris)

**INTERCITÉS** (standard medium and long-distance trains)

**Keolis** (urban and suburban transport)



## SNCF VOYAGES

**High-speed passenger rail operators**

- TGV
- iDTGV
- OUIGO
- Eurostar
- Thalys
- TGV Lyria
- DB/SNCF en coopération
- NTV
- Elipsos
- TGV Italie
- Westbahn

**Long-distance coach travel**  
- iDBUS



## SNCF GEODIS

**Geodis**  
STVA

**Rail freight (TFM)**  
- Fret SNCF  
- Captrain  
- VFLI  
- VIA  
- Multi-modal transport business

**Gestionnaires d'actifs**  
- Ermewa  
- Akiem

## GARES & CONNEXIONS

**Station management & development in France**

**Multi-disciplinary operations-building and outfitting facilities**  
- AREP  
- Parvis  
- A2C

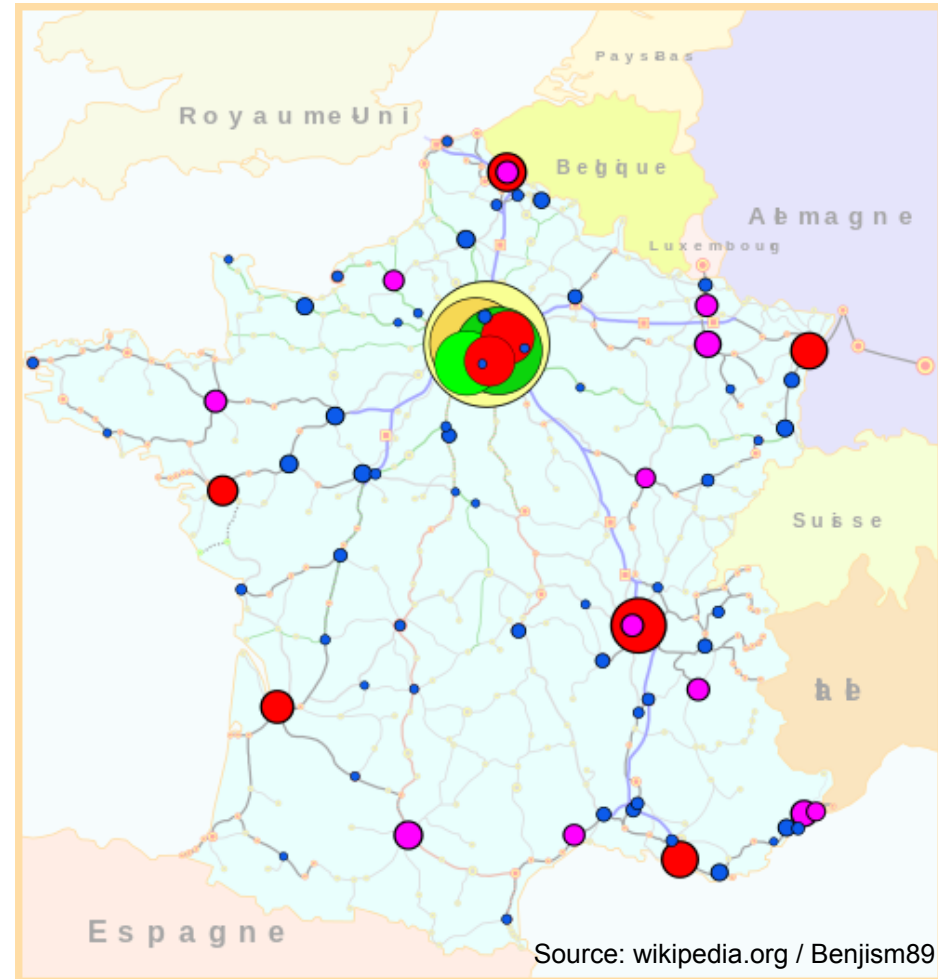


# Operations Research at SNCF

- Long story
  - First OR studies in the 60s
- A great variety of problems
  - Rolling stock unit rostering
  - Workforce scheduling
  - Maintenance optimization
  - ...
- Two dedicated teams
  - Innovation & Research
  - IT

# Major train stations ...

- 15 stations > 10 million passengers / year
  - 6 in Paris, others in large French cities
  - Gare du Nord: ~200 million / year
    - Highest traffic in Europe, 2<sup>nd</sup> in the world



... associated with major railway sites ...

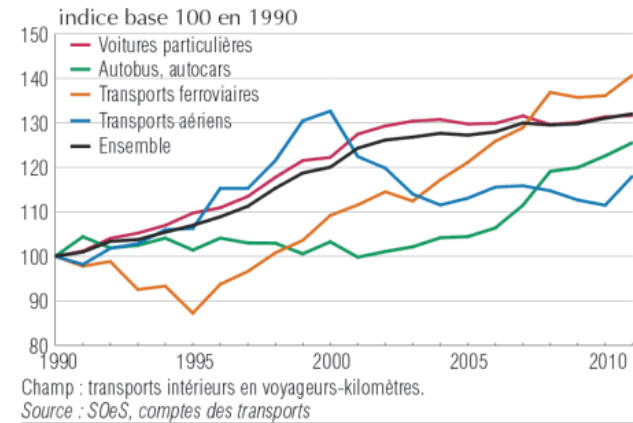
- ... generally surrounded by maintenance facilities and yards



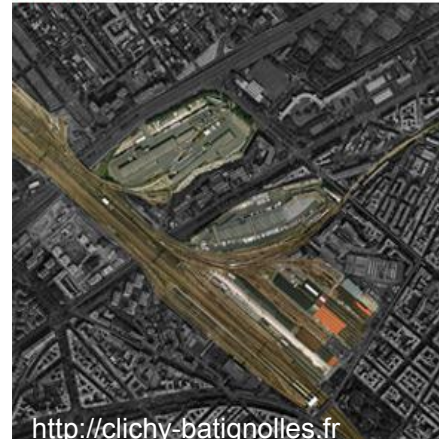
## ... close to saturation

- Traffic increased significantly in recent years
  - Projections forecast further increase
- Some tracks are closed in urban areas
  - Industrial areas converted into new constructions

Évolution des volumes de transports intérieurs de voyageurs de 1990 à 2011



AVANT

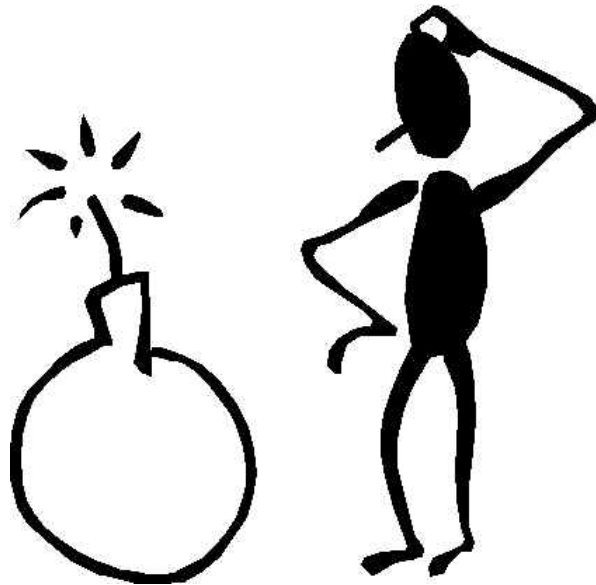


APRÈS



And NOW

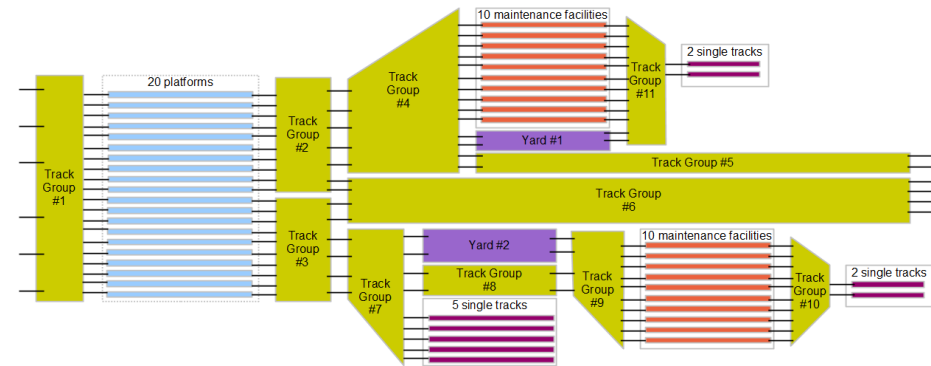
The problem itself !





# Overview of the problem

- Resources: tracks within a local perimeter
  - Train station
  - Maintenance facilities
  - Yards
  - Tracks (moves, parking)



- Trains
  - Entering the system (Arrivals)
  - Exiting (Departures)

# Overview of the problem

- Maintenance
  - Distance / time before maintenance of each arriving train
  - Requirements (distance / time) for each departure
  - Maintenance operations
    - Type D or T
    - Can be performed only on maintenance facilities
- Joint-arrival and joint-departures
  - Assembled trains coming / leaving together
  - Junction and disjunction operations to assemble and disassemble trains



# Transitions between resources

- Tracks are linear resources
  - Two sides :  $A$  and  $B$
- Gates to enter/exit a resource
  - At most one on each side for “individual” tracks
    - $A1 ; B1$
  - No restriction for yards and track groups
    - As many gates as tracks :  $A1, \dots, An ; B1, \dots, Bm$
    - One gate to be chosen among all possibilities
  - Ordered on each side of the resource
    - Physical position of tracks



# Different types of resources

- Platform
  - Tracks in train station
  - Required for arrival and departures
    - Boarding / unboarding of passengers
  - At most one entry point on each side



# Different types of resources

- Maintenance facility
  - Track dedicated to operations either on distance or on time
  - At most one entry point on each side



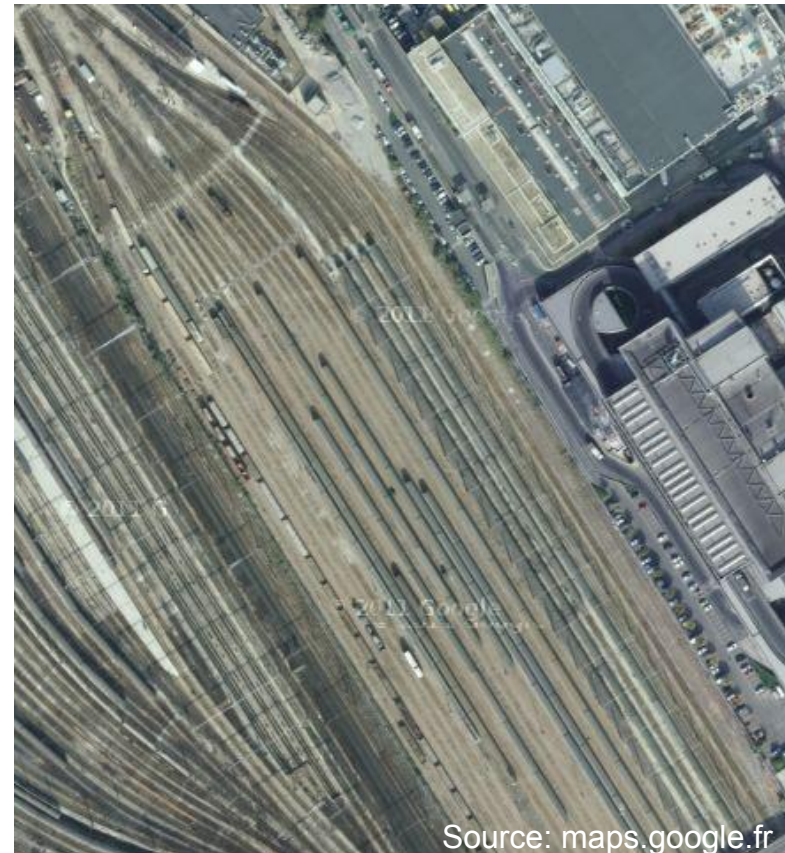
# Different types of resources

- Single track
  - Track outside station with no particular dedication
  - May be used for parking or to perform some moves
  - At most one entry point on each side



# Different types of resources

- Yard
  - Set of tracks dedicated to storage of trains
  - Potentially a few entry points on each side
  - Capacity: number of trains
  - No internal details provided



Source: maps.google.fr

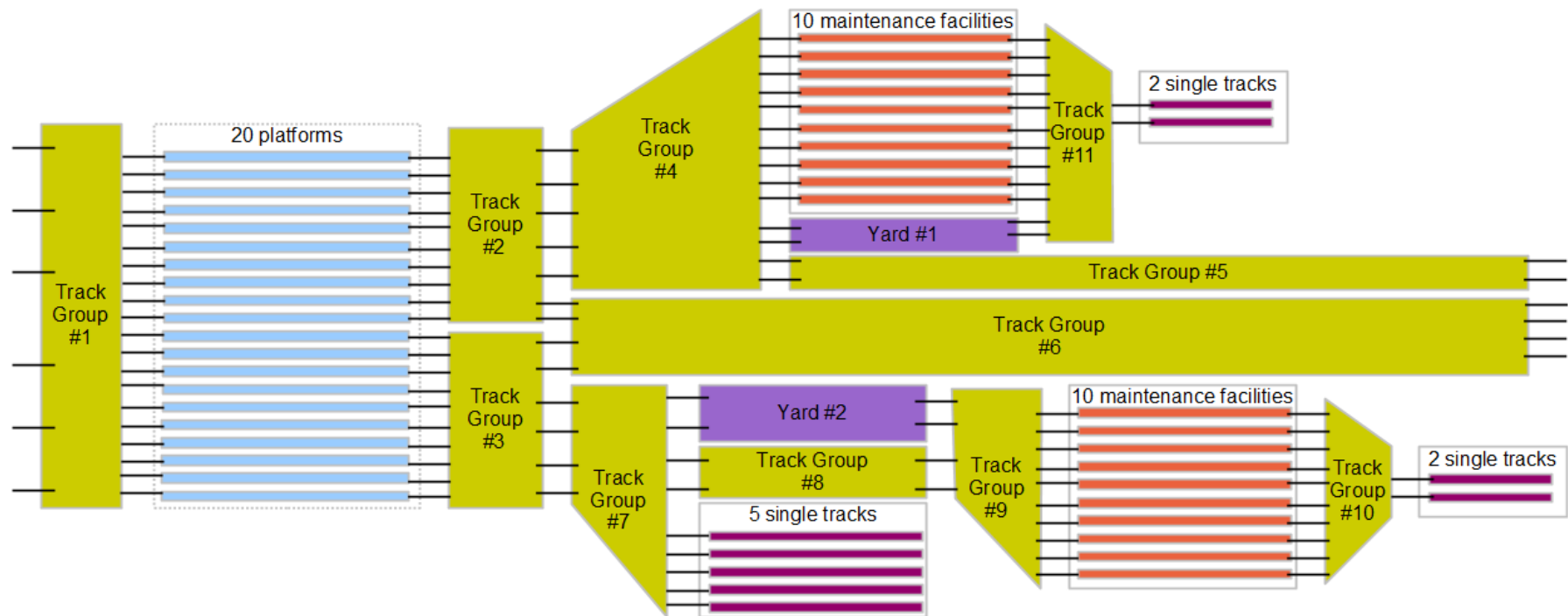
# Different types of resources

- Track group
  - Set of tracks dedicated to train moves
  - Potentially a few entry points on each side
  - No internal detail provided
  - Fixed travel time
  - Headway time: minimum time between two trains on intersecting paths
  - No reverse allowed





# System: composed of all types of resources



# Expected solutions

- Over a  $n$ -day horizon (up to 2 weeks)
- Propose a schedule for each train
  - Train: visit in the system of a rolling stock unit
  - Either linked with an arrival
  - Or initially in the system
- Schedule of  $t$ 
  - List of events associated with  $t$ 
    - Enter/exit system
    - Enter/exit resource
    - Begin/end operation

Train	Time	Event type	Resource	Gate	Complement
...	...	...	...	...	...
Train9	d <sub>2</sub> 07:35:00	BegJunction	Yard5		Train9+Train12
Train9	d <sub>2</sub> 07:38:00	EndJunction	Yard5		Train1+Train9+Train12
Train9	d <sub>2</sub> 09:02:00	ExitResource	Yard5	B3	
Train9	d <sub>2</sub> 09:02:00	EnterResource	TrGroup7	B1	
Train9	d <sub>2</sub> 09:04:00	ExitResource	TrGroup7	A2	
Train9	d <sub>2</sub> 09:04:00	EnterResource	TrGroup8	A1	
Train9	d <sub>2</sub> 09:09:00	ExitResource	TrGroup8	B2	
Train9	d <sub>2</sub> 09:09:00	EnterResource	Facility1	A1	
Train9	d <sub>2</sub> 09:09:00	BegMaintenance	Facility1		"D"
Train9	d <sub>2</sub> 11:09:00	EndMaintenance	Facility1		"D"
Train9	d <sub>2</sub> 11:45:00	ExitResource	Facility1	A1	
Train9	d <sub>2</sub> 11:45:00	EnterResource	TrGroup8	B3	
Train9	d <sub>2</sub> 11:50:00	ExitResource	TrGroup8	A8	
Train9	d <sub>2</sub> 11:50:00	EnterResource	Platform14	A1	
Train9	d <sub>2</sub> 12:20:00	Departure	Platform14		Departure35
Train9	d <sub>2</sub> 12:20:00	ExitResource	Platform14	A1	
Train9	d <sub>2</sub> 12:20:00	EnterResource	TrGroup9	A2	
Train9	d <sub>2</sub> 12:25:00	ExitResource	TrGroup9	B2	
Train9	d <sub>2</sub> 12:25:00	ExitSystem	TrGroup9		

Train	Time	Event type	Resource	Gate	Complement
...	...	...	...	...	...
Train12	d <sub>2</sub> 07:35:00	BegJunction	Yard5		Train9+Train12
Train12	d <sub>2</sub> 07:38:00	EndJunction	Yard5		Train1+Train9+Train12
Train12	d <sub>2</sub> 09:02:00	ExitResource	Yard5	B3	
Train12	d <sub>2</sub> 09:02:00	EnterResource	TrGroup7	B1	
Train12	d <sub>2</sub> 09:04:00	ExitResource	TrGroup7	A2	
Train12	d <sub>2</sub> 09:04:00	EnterResource	TrGroup8	A1	
Train12	d <sub>2</sub> 09:09:00	ExitResource	TrGroup8	B2	
Train12	d <sub>2</sub> 09:09:00	EnterResource	Facility1	A1	
Train12	d <sub>2</sub> 09:09:00	BegMaintenance	Facility1		"D"
Train12	d <sub>2</sub> 11:09:00	EndMaintenance	Facility1		"D"
Train12	d <sub>2</sub> 11:45:00	ExitResource	Facility1	A1	
Train12	d <sub>2</sub> 11:45:00	EnterResource	TrGroup8	B3	
Train12	d <sub>2</sub> 11:50:00	ExitResource	TrGroup8	A8	
Train12	d <sub>2</sub> 11:50:00	EnterResource	Platform14	A1	
Train12	d <sub>2</sub> 12:20:00	Departure	Platform14		Departure36
Train12	d <sub>2</sub> 12:20:00	ExitResource	Platform14	A1	
Train12	d <sub>2</sub> 12:20:00	EnterResource	TrGroup9	A2	
Train12	d <sub>2</sub> 12:25:00	ExitResource	TrGroup9	B2	
Train12	d <sub>2</sub> 12:25:00	ExitSystem	TrGroup9		

Train1	d <sub>2</sub> 07:23:00	EnterResource	TrGroup6	B4	
Train1	d <sub>2</sub> 07:23:00	ExitResource	TrGroup6	A3	
Train1	d <sub>2</sub> 07:23:00	EnterResource	Yard5	A2	
Train1	d <sub>2</sub> 07:35:00	BegJunction	Yard5		Train1 Train1+Train9+Train12
Train1	d <sub>2</sub> 07:38:00	EndJunction	Yard5		
Train1	d <sub>2</sub> 09:02:00	ExitResource	Yard5	B3	
Train1	d <sub>2</sub> 09:02:00	EnterResource	TrGroup7	B1	
Train1	d <sub>2</sub> 09:04:00	ExitResource	TrGroup7	A2	
Train1	d <sub>2</sub> 09:04:00	EnterResource	TrGroup8	A1	
Train1	d <sub>2</sub> 09:09:00	ExitResource	TrGroup8	B2	
Train1	d <sub>2</sub> 09:09:00	EnterResource	Facility1	A1	
Train1	d <sub>2</sub> 09:09:00	BegMaintenance	Facility1		"D" "D"
Train1	d <sub>2</sub> 11:09:00	EndMaintenance	Facility1		
Train1	d <sub>2</sub> 11:45:00	ExitResource	Facility1	A1	
Train1	d <sub>2</sub> 11:45:00	EnterResource	TrGroup8	B3	
Train1	d <sub>2</sub> 11:50:00	ExitResource	TrGroup8	A8	
Train1	d <sub>2</sub> 11:50:00	EnterResource	Platform14	A1	
Train1	d <sub>2</sub> 12:20:00	Departure	Platform14		Departure34
Train1	d <sub>2</sub> 12:20:00	ExitResource	Platform14	A1	
Train1	d <sub>2</sub> 12:20:00	EnterResource	TrGroup9	A2	
Train1	d <sub>2</sub> 12:25:00	ExitResource	TrGroup9	B2	
Train1	d <sub>2</sub> 12:25:00	ExitSystem	TrGroup9		

Input data

Decisions

Joint-Departure  
(from input data)



# Main decisions to make

- Assign
  - A platform for each arrival/departure
  - A train for each departure
  - A suitable resource for each operation (maintenance, junction/disjunction)
- Operations performed by trains
  - Maintenance
  - Junction/disjunction
- At which time
  - Trains move from one resource to another one
  - Trains start operations

# Objectives

- Lexicographic multi-objective evaluation
  1. Min number of uncovered departures
  2. Min number of conflicts and yard overload
  3. Min operational cost
    - Over-maintenance cost
    - Junction/disjunction cost
    - Platform usage
    - Non-satisfied preferred platform assignment cost
    - Non-satisfied train reuse cost

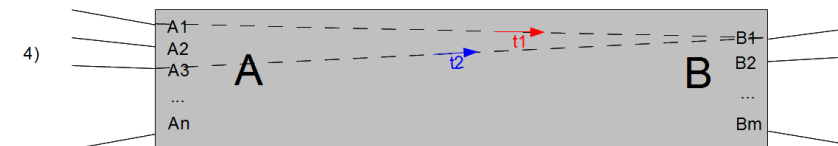
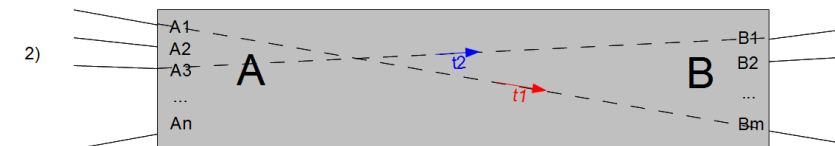
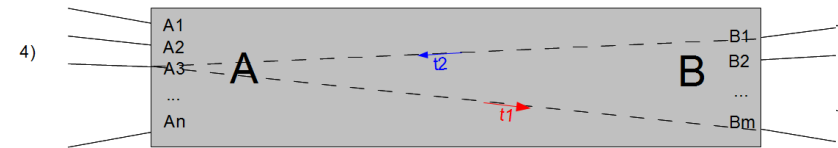
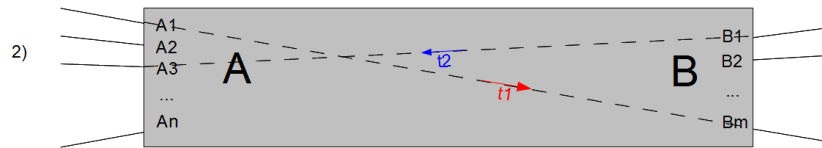
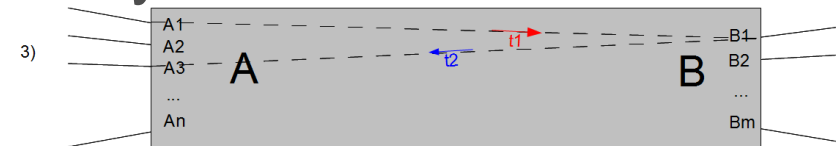
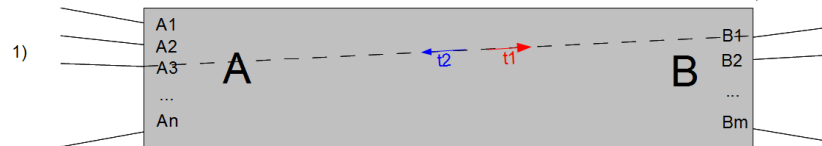
# Main types of constraints

- Schedule properties
  - Enter/exit resources, transitions between resources
  - Duration of operations
- Assignment
  - Trains to departures
  - Maintenance requirements for departures
- Resource usage
  - Limited capacities / length of tracks
  - Train order
- Assembled trains
  - Train position on platform

# Conflicts between two moves

- No conflict if paths do not intersect
  - E.g.: A1-B1 and A6-B3 can be performed simultaneously
- Otherwise, conflicts detected in 2 cases:

– Moves in same direction, headway not satisfied



– Moves in opposite direction, headway not satisfied

- $|h_1 - h_2| < T + H$

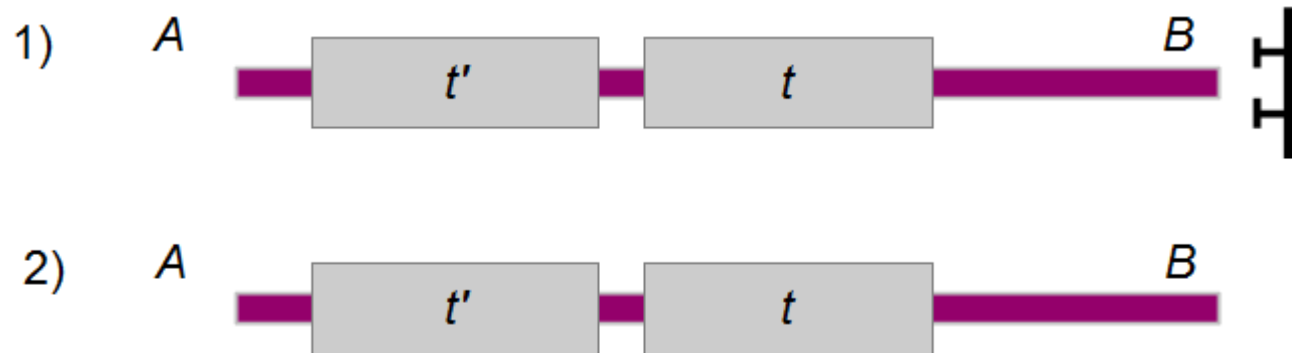
# Track groups

- Conflict detection: simplified model
  - No internal representation
    - Number of tracks, location of switches, signaling...
  - No perfect correspondence with conflicts that occur in practice
    - Only estimation of situations to avoid
    - Some situations with conflicts could be feasible in practice
    - Absence of conflicts does not mean 100% of moves are feasible



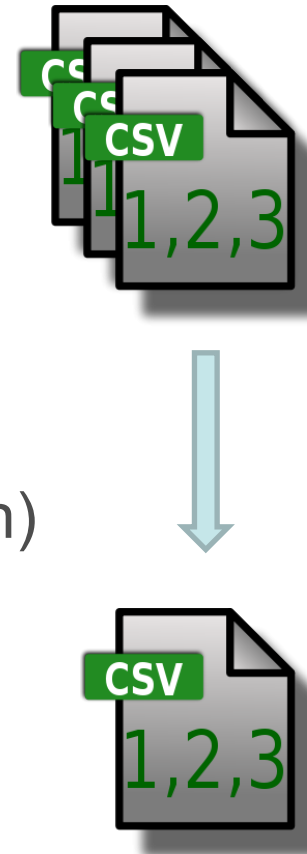
# Position of trains on individual tracks

- Order of enter/exit of trains must be consistent



# Your software, in practice

- Input: each instance composed of several csv files
  - Arrivals
  - Departures
  - Resource description
  - Compatibilities
  - Preferences
  - General parameters (costs, horizon)
  - ...
- Output: one csv file
  - Schedules of all trains
  - Sorted by train, then by event time



# Typical volume of data

- Number of days in the horizon: 1 to 14.
- Initial trains: 10 to 100.
- Arrivals: 50 to 500 per day.
- Departures: 50 to 500 per day.
- Train categories: 1 to 10.
- Single tracks: 0 to 50.
- Platforms: 10 to 50.
- Maintenance facilities: 5 to 50.
- Track groups: 5 to 20.
- Yards: 1 to 5.



# Your software, in practice

- Allowed computation time: 10 mn
  - From executable launch to output file generation
- Checker can be used to evaluate solutions
  - Provided early September
  - Evaluates
    - Feasibility of solutions
    - Objective functions
  - Open Source
    - Evaluation made transparent
    - Inconsistancies between problem description and checker (if any) can be detected and reported to SNCF via the forum dedicated to this challenge

# Conclusion

- Industrial problem with real issues to solve
  - Integrated approach
  - Rich model, broad range of possibilities
  - Nasty constraints: be smart !
- Prospective approach
  - In practice, problem divided into many sub-problems, solved sequentially (and mostly manually) at SNCF
  - No internal tool to compare with
  - Analysis of solutions by experts: changes might be introduced at the end of qualification