

# **A new Constraint Based Scheduling model for real-time Railway Traffic Management Problem using conditional Time-Intervals**

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**IFSTTAR**

# Context

- Real-time Railway Traffic Management Problem (rtRTMP)
  - Decisions : train schedules and local re-routing
  - Criterion : reduce the secondary delays of trains due to conflicts
- Most popular approaches for rtRTMP :
  - Integer programming (IP)
  - Mixed-integer programming (MIP)
  - Graph
- Constraint programming (CP) : seldom used
  - Previous model  Rodriguez, J. (2007)

# Motivation

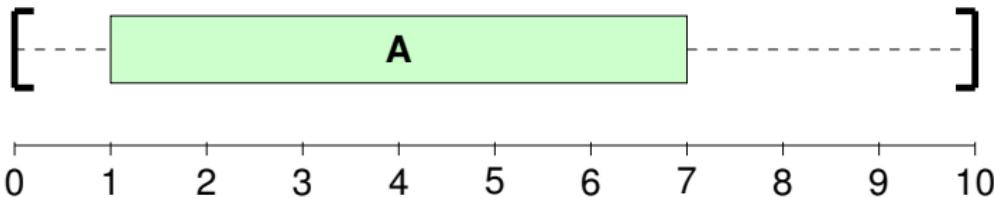
- Since, a new concept is proposed in CP for scheduling :
  - **Optional Time-Intervals**  Laborie, P. and Rogerie, J. (2008)
  - **Hybrid approach** for solving (Linear Programming, Artificial Intelligence)
    - Failure directed search  Vilim, P., Laborie P., Shaw, P. (2015)
    - Linear relaxation  Laborie, P. and Rogerie, J. (2016)
    - Objective landscape  Laborie, P. (2018)
- IBM CP Optimizer library.

# Objectives

Research objectives :

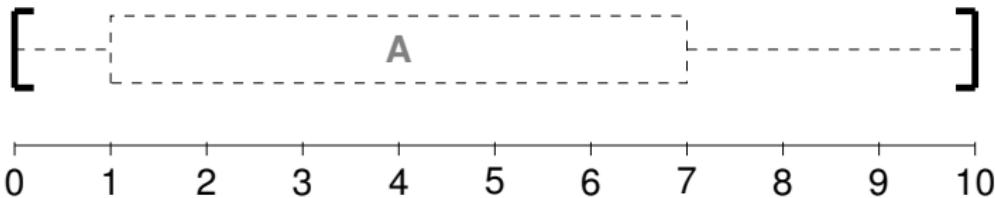
- New CP formulation of the rtRTMP using the concept of Time-Intervals : **RECIFE-Intervals**
- Evaluate and compare its performances with other approaches (e.g. RECIFE-MILP)

# Optional Time-Interval Concept



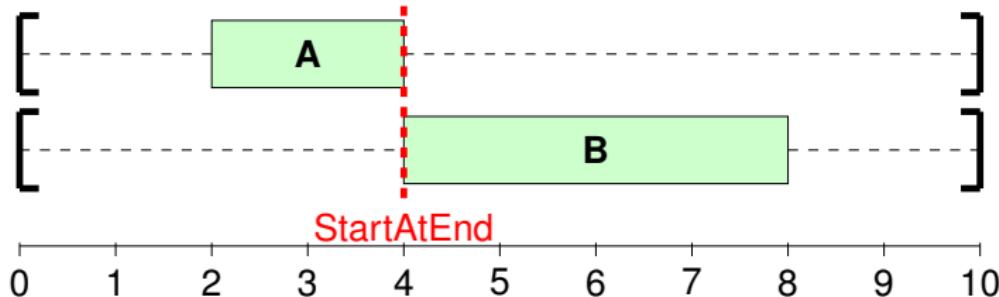
- Used for modeling an interval of time during which a property holds
- Aggregation of :
  - Two temporal variables : start, end
  - One logical variable : presence

# Optional Time-Interval Concept



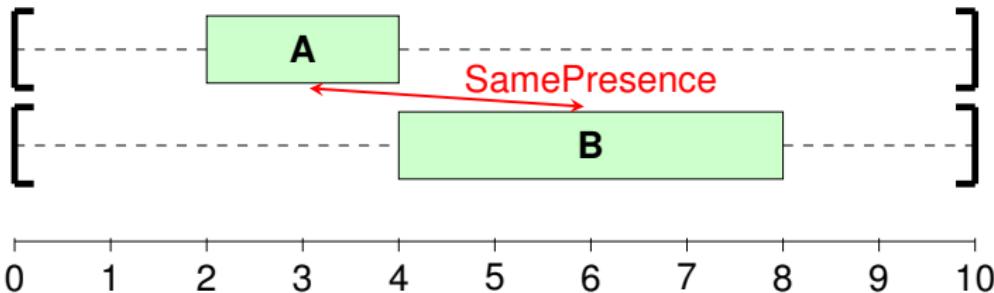
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# Optional Time-Interval Concept



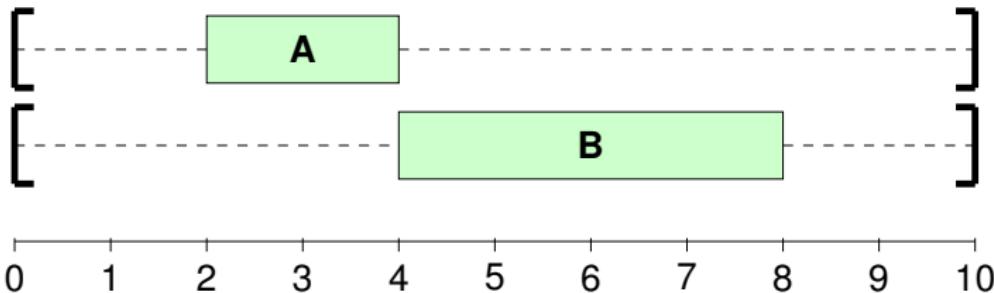
- Relations between intervals:
  - Temporal constraints

# Optional Time-Interval Concept



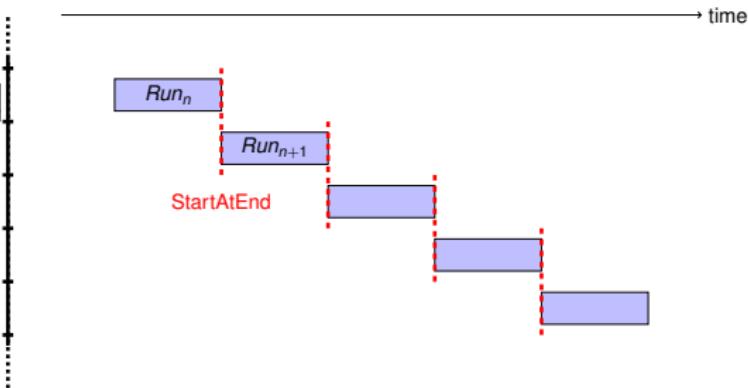
- Relations between intervals:
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  - Logical constraints

# Optional Time-Interval Concept



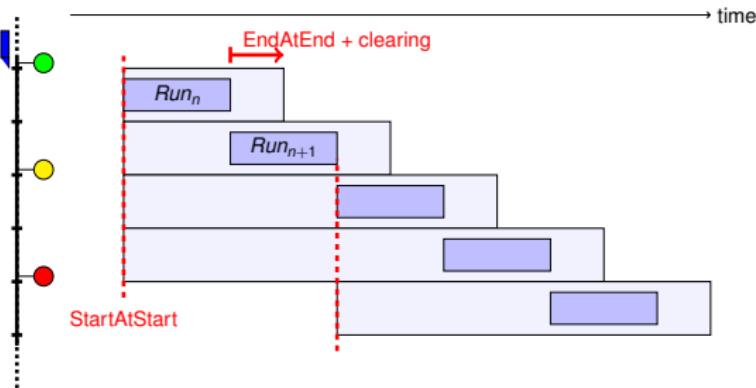
- Relations between intervals:
  - Temporal constraints  $\Rightarrow$  Simple Temporal Network
  - Logical constraints  $\Rightarrow$  2-satisfiability Network
  - Propagation between both networks

# RECIFE-Intervals



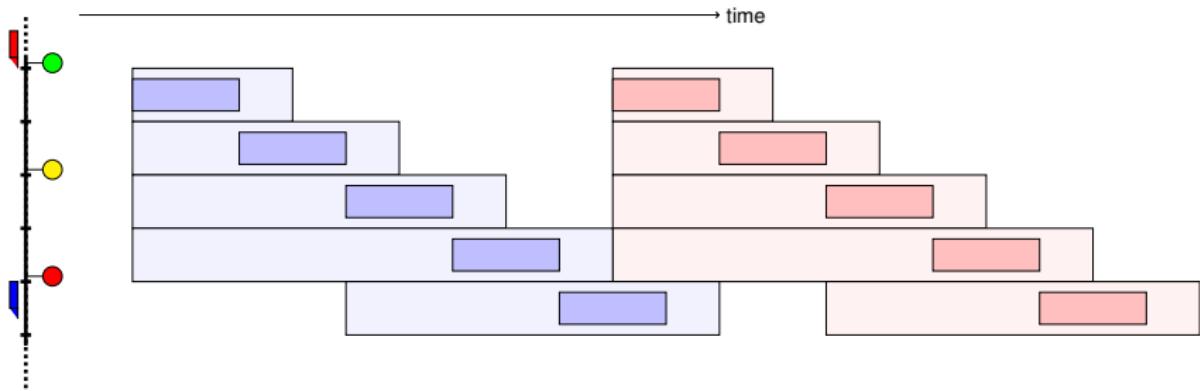
- "Run" Intervals
  - Running of the head of the train through the track detection sections

# RECIFE-Intervals



- "Reservation" Intervals:
  - Blocking time stairways reservation of the track detection sections

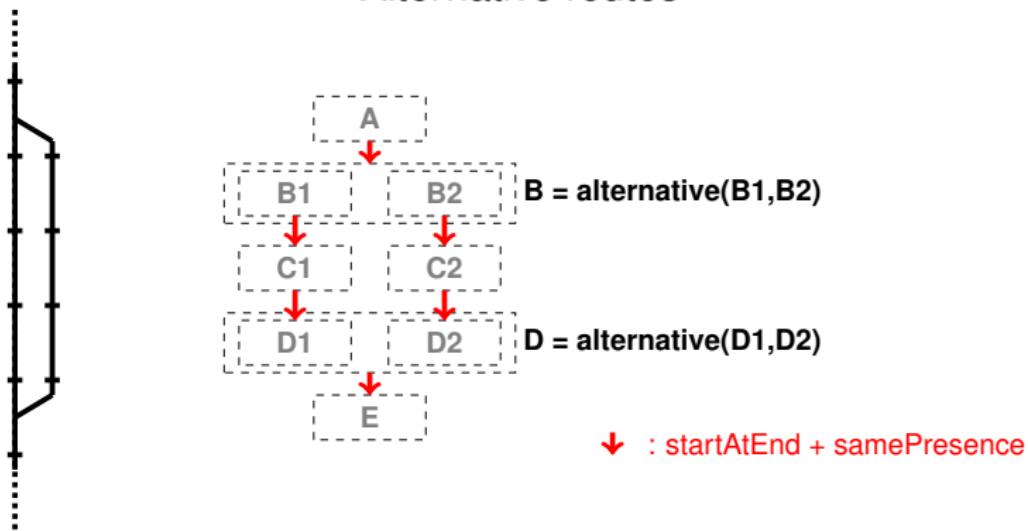
# RECIFE-Intervals



- No overlapping of reservation intervals  
⇒ Minimum spacing between trains

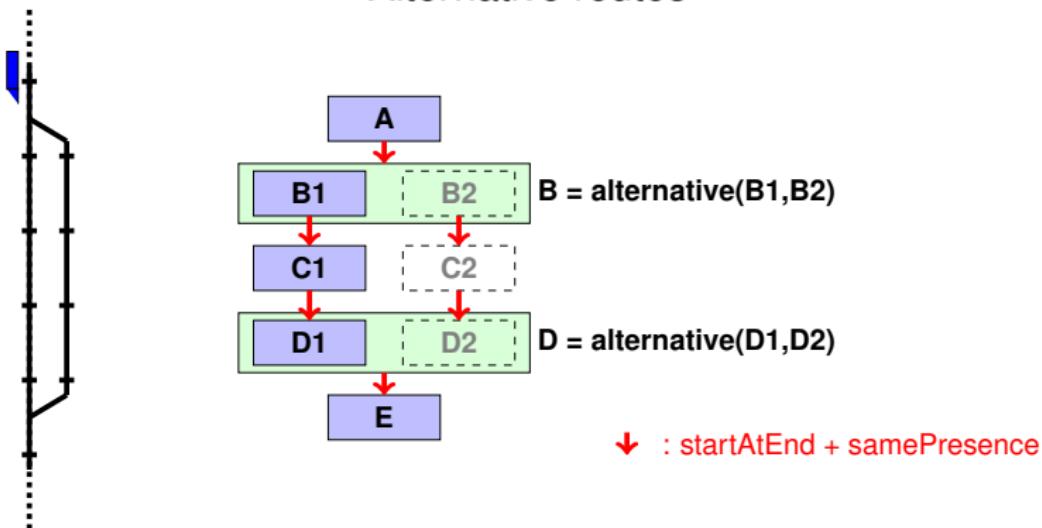
# RECIFE-Intervals

## Alternative routes



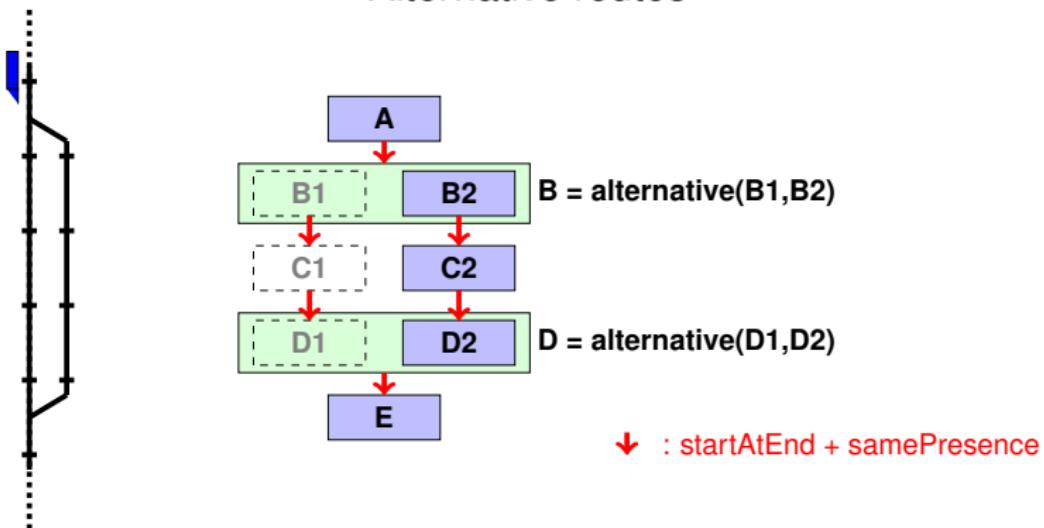
# RECIFE-Intervals

## Alternative routes



# RECIFE-Intervals

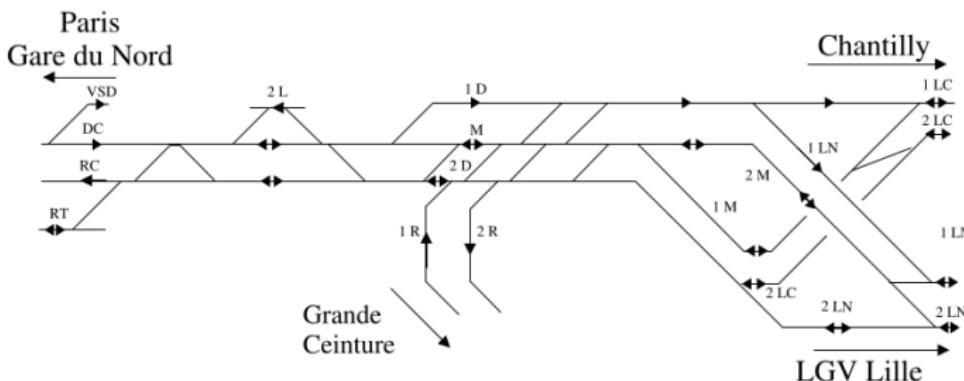
## Alternative routes



# Experiments

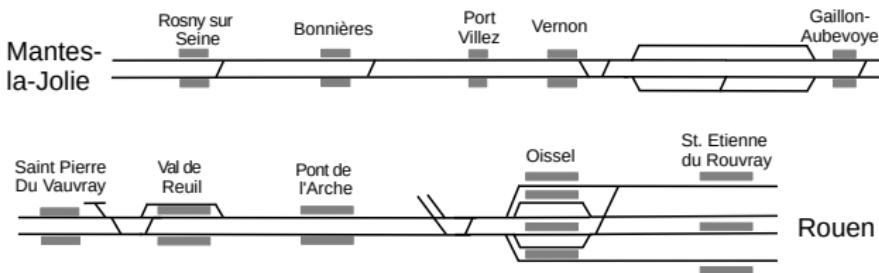
- Benchmark between **RECIFE-Intervals** and **RECIFE-MILP**  Pellegrini, P., Marlière, G., and Rodriguez, J. (2014)
  - Two-step approach :
    1. Limit of 10s CPU time : Fixed routes
    2. Limit of 180s CPU time : All route alternatives
- Horizon size variation :
  - **12 time intervals** : 10 mn to 120 mn ( $\Delta = 10$  mn)
  - 30 perturbation scenarios with 20% of randomly selected trains delayed
- 4 case studies

# Case studies #1



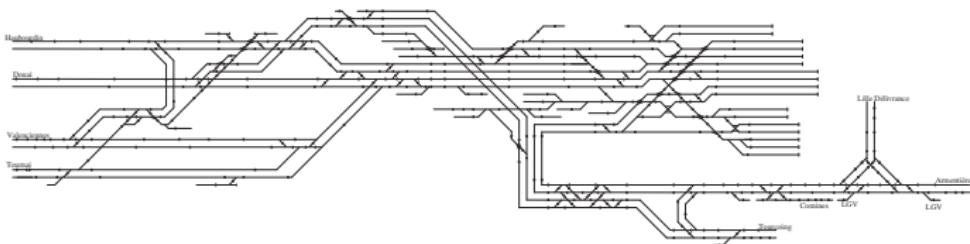
Junction			Pierrefitte-Gonesse		
Length (km)	Routes	Blocks	Track Circuits	Stations	Platforms
15	37	79	89	0	0
Trains/Day	Routes/Train	Rolling stock roster			
336	5-13	0			

## Case studies #2



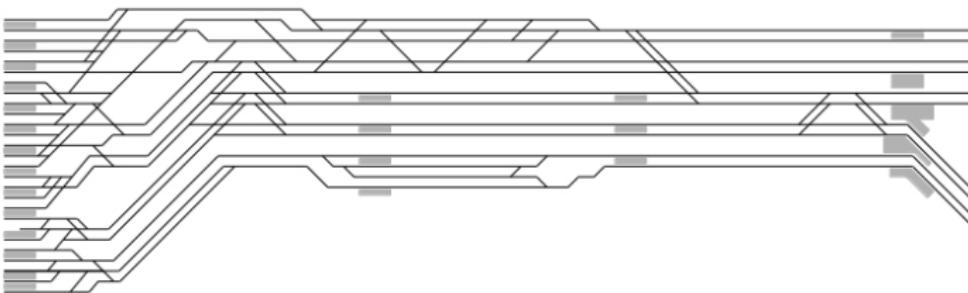
Line			MLJ-Rouen		
Length (km)	Routes	Blocks	Track Circuits	Stations	Platforms
80	187	157	236	13	23
Trains/Day	Routes/Train	Rolling stock roster			
237	1-24	6			

# Case studies #3



Station			Lille-Flandres		
Length (km)	Routes	Blocks	Track Circuits	Stations	Platforms
7	<b>2409</b>	<b>829</b>	<b>299</b>	1	17
Trains/Day	Routes/Train	Rolling stock roster			
589	<b>1-71</b>	298			

## Case studies #4

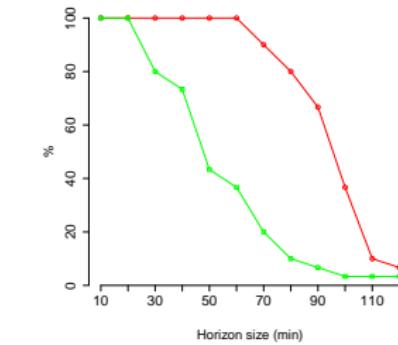


Station			Paris Saint-Lazare		
Length (km)	Routes	Blocks	Track Circuits	Stations	Platforms
4.5	84	197	212	4	51
Trains/Day	Routes/Train	Rolling stock roster			
1212	1-9	606			

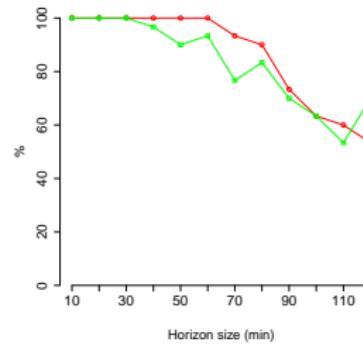
# Experimental Results

## RECIFE-Intervals vs RECIFE-MILP

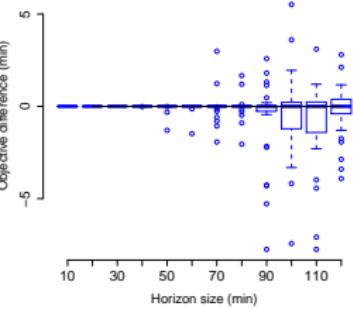
Proof of optimality



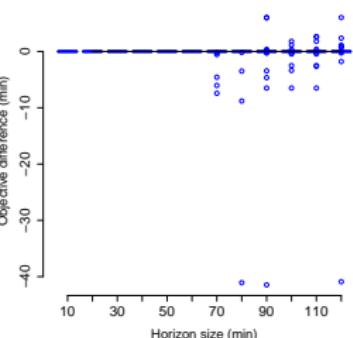
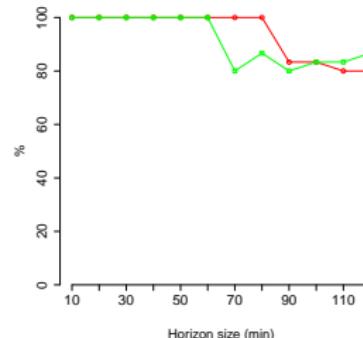
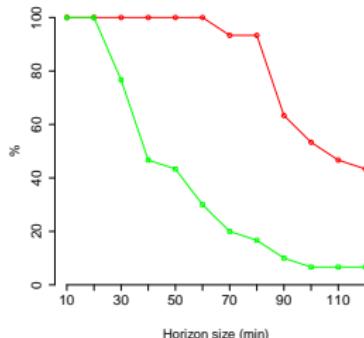
Best Solution



Objectif MILP - Intervals



#1 Gonesse

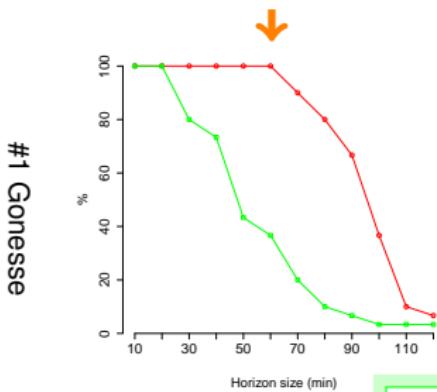


#2 MLJ-Rouen

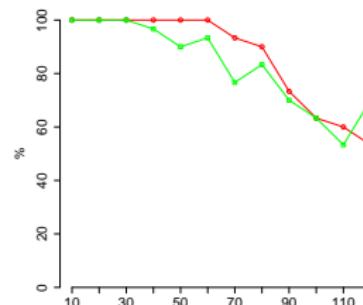
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## RECIFE-Intervals vs RECIFE-MILP

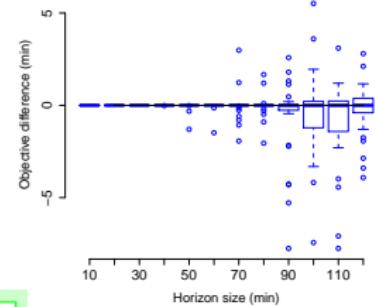
Proof of optimality



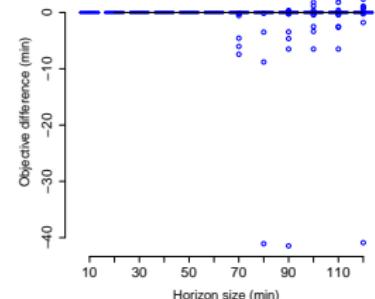
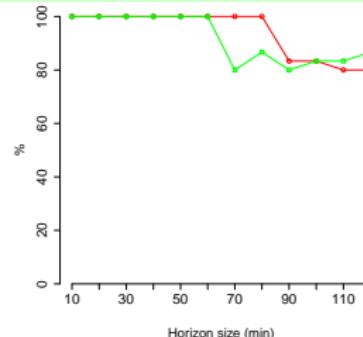
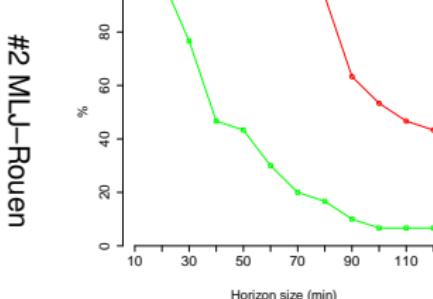
Best Solution



Objectif MILP - Intervals



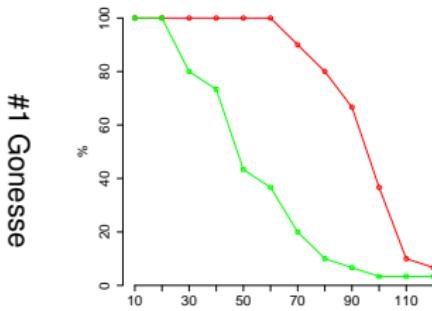
Less able to prove optimality



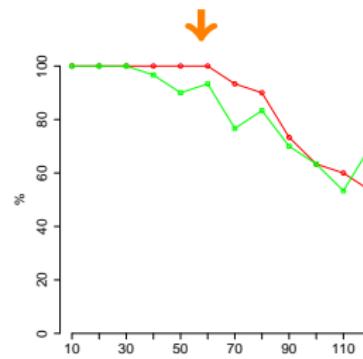
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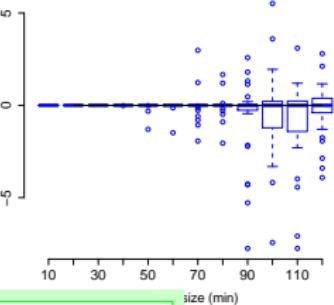
Proof of optimality



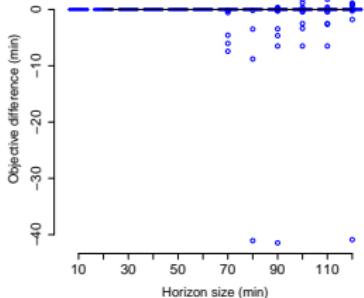
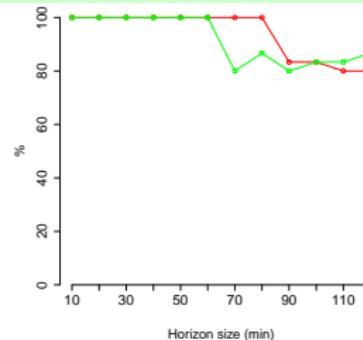
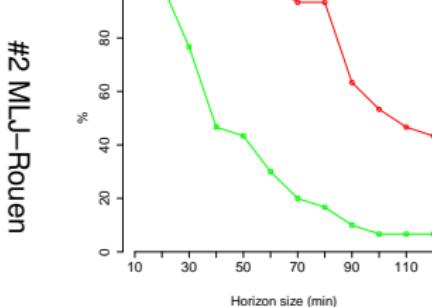
Best Solution



Objectif MILP - Intervals



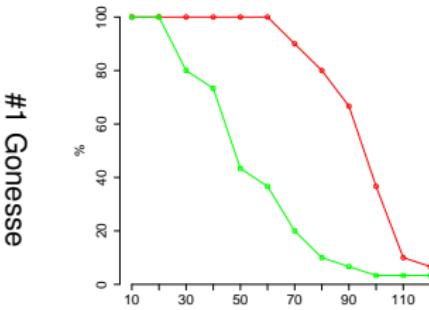
Some sub-optimal solutions on medium size instances



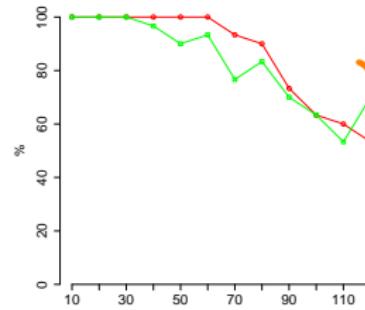
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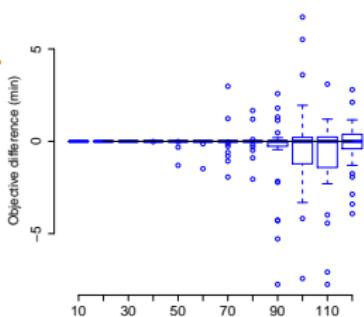
Proof of optimality



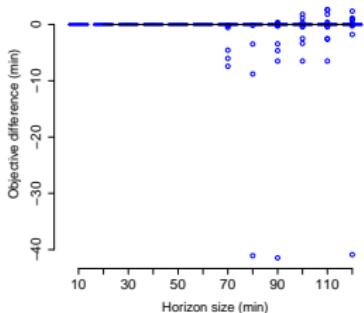
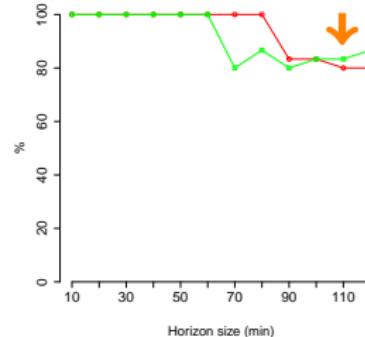
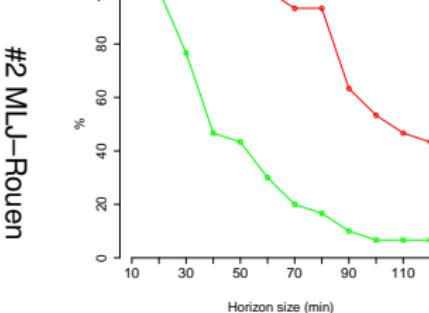
Best Solution



Objectif MILP - Intervals



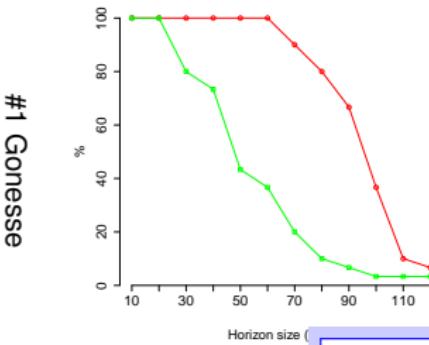
RECIFE-Intervals has better performances on large instances



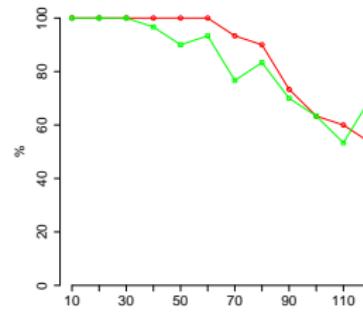
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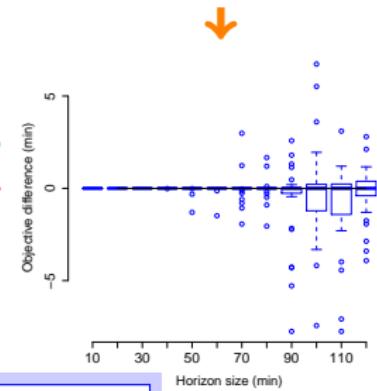
Proof of optimality



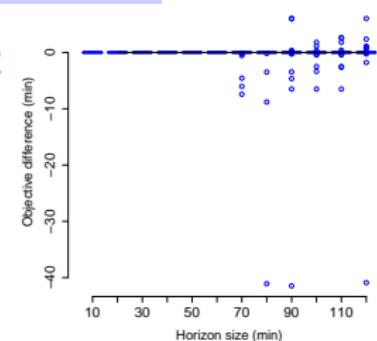
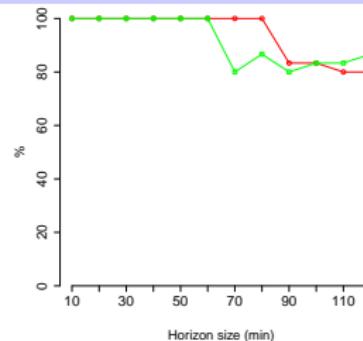
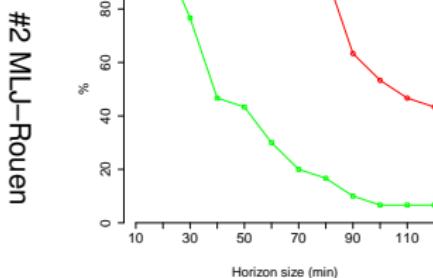
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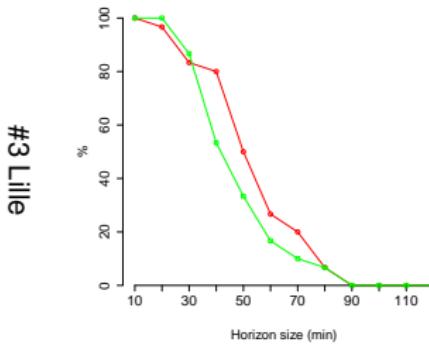
Few difference in terms of solution quality



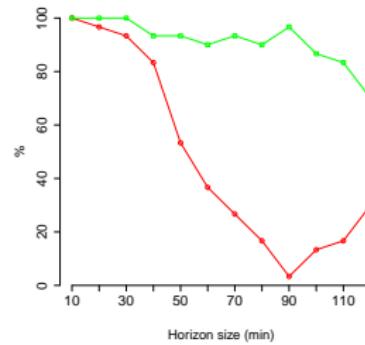
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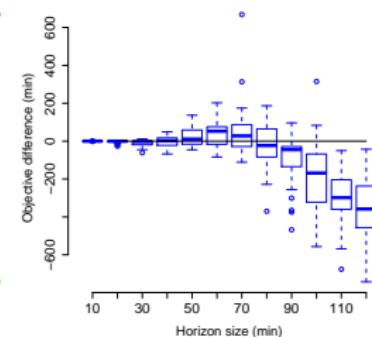
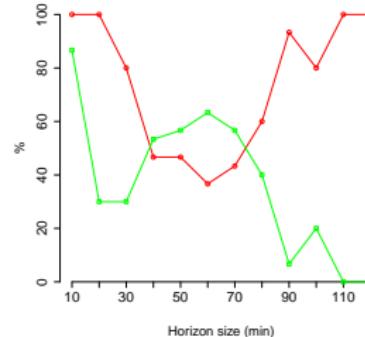
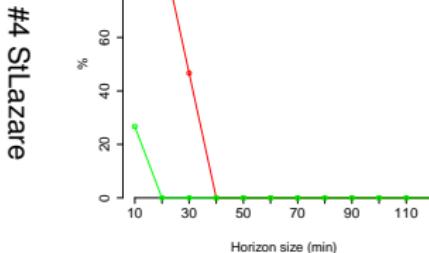
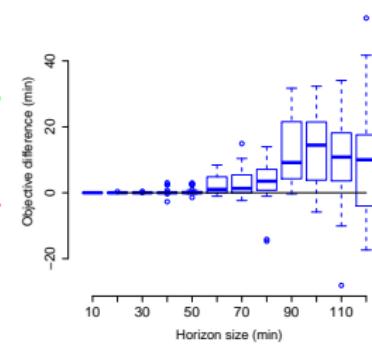
Proof of optimality



Best Solution



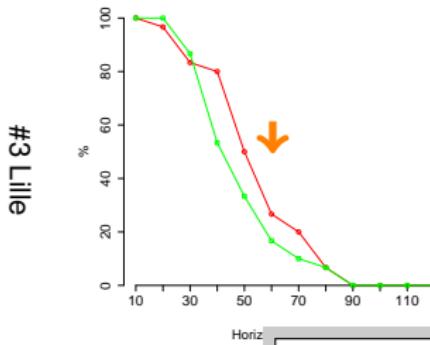
Objectif MILP - Intervals



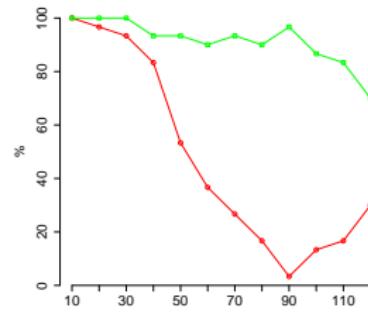
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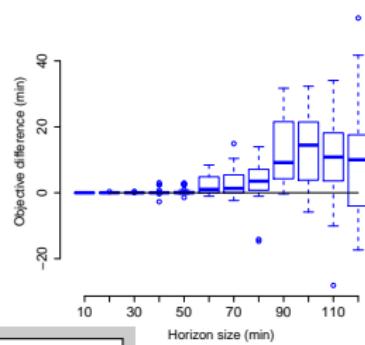
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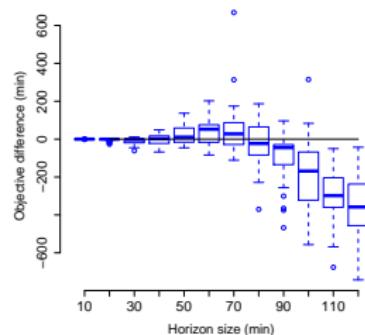
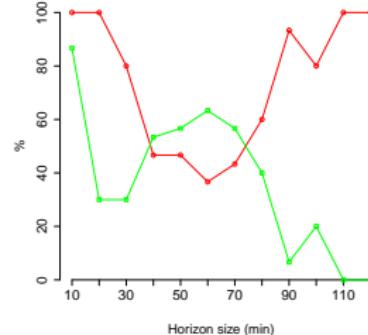
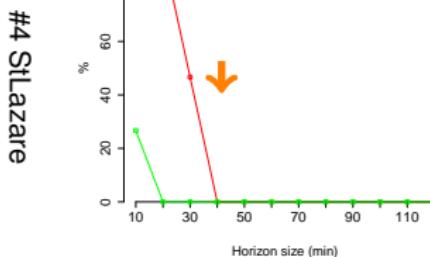
Best Solution



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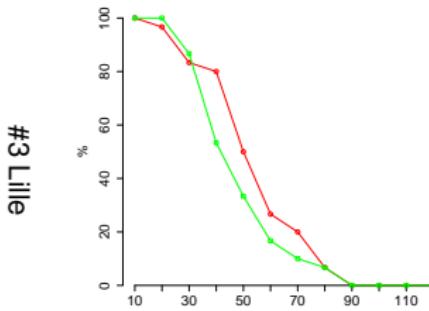
Difficult cases  $\Rightarrow$  optimality rarely proved



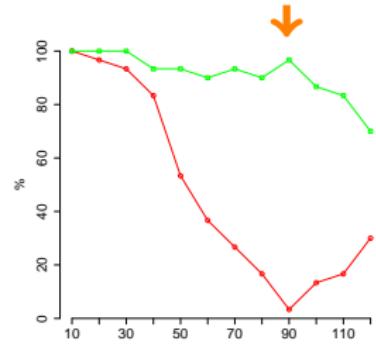
# Experimental Results

## RECIFE-Intervals vs RECIFE-MILP

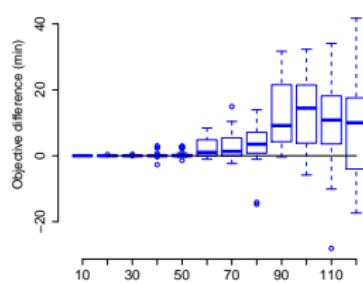
Proof of optimality



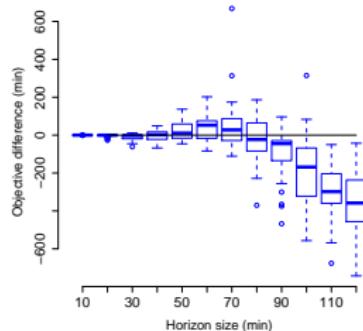
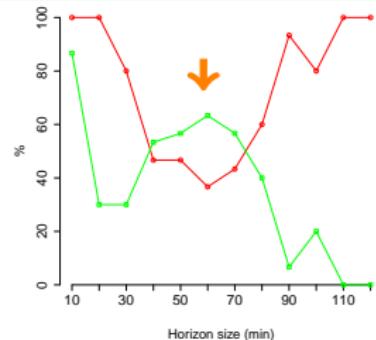
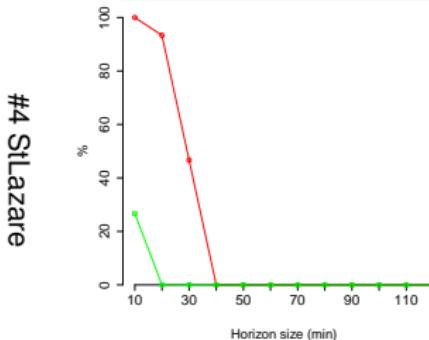
Best Solution



Objectif MILP - Intervals



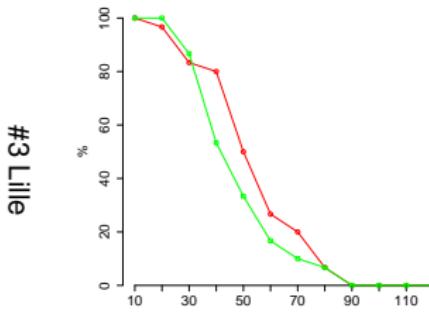
RECIFE-Intervals becomes more efficient on difficult instances



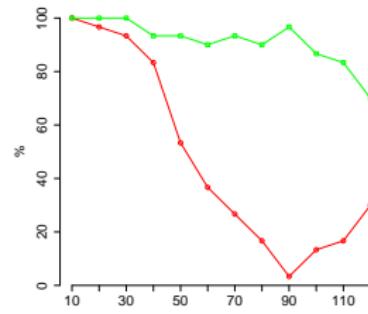
# Experimental Results

## RECIFE-Intervals vs RECIFE-MILP

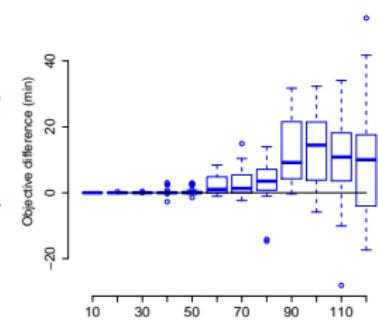
Proof of optimality



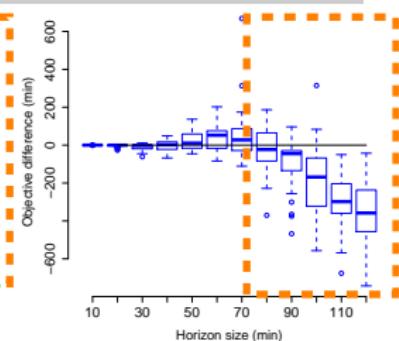
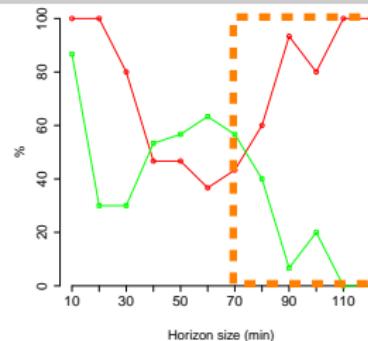
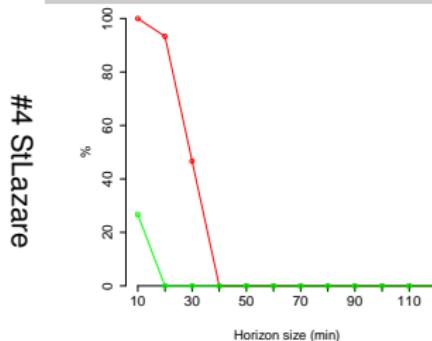
Best Solution



Objectif MILP - Intervals



Too difficult : MILP doesn't provide solution except the fixed-route solution



# Conclusion

- New formulation of a Constraint Based Scheduling of the Real-time Railway Traffic Management Problem
- Concept of Time-interval variables simplifies the formulation of optional activities
- Preliminary results show good performance of the proposed approach in comparison with the state-of-the art RECIFE-MILP algorithm
- **Perspectives :**
  - Specific solution methods
  - Deep analysis of weaknesses and strengths of RECIFE-MILP and RECIFE-Intervals  
⇒ Hybrid solution approach