


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

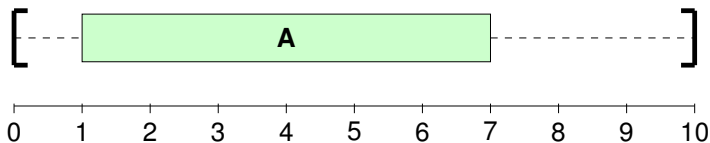
- Since, a new concept is proposed in CP for scheduling :
 - **Optional Time-Intervals**  Laborie, P. and Rogerie, J. (2008)
 - **Hybrid approach** for solving (Linear Programming, Artificial Intelligence)
 - Failure directed search  Vilim, P., Laborie P., Shaw, P. (2015)
 - Linear relaxation  Laborie,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

Objectives

Research objectives :

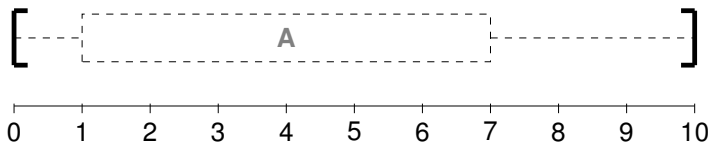
- New CP formulation of the rtRTMP using the concept of Time-Intervals : **RECIFE-Intervals**
- Evaluate and compare its performances with other approaches (e.g. RECIFE-MILP)

Optional Time-Interval Concept



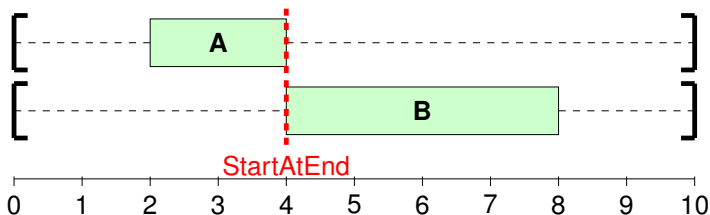
- Used for modeling an interval of time during which a property holds
- Aggregation of :
 - Two temporal variables : start, end
 - One logical variable : presence

Optional Time-Interval Concept



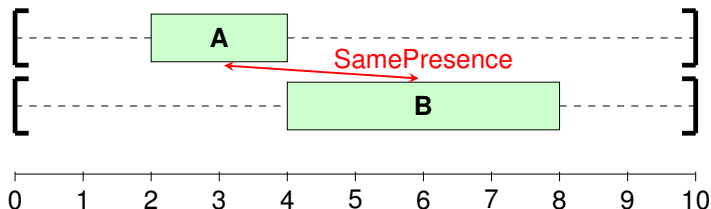
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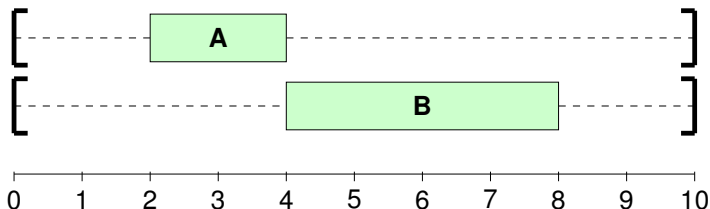
- Relations between intervals:
 - Temporal constraints

Optional Time-Interval Concept



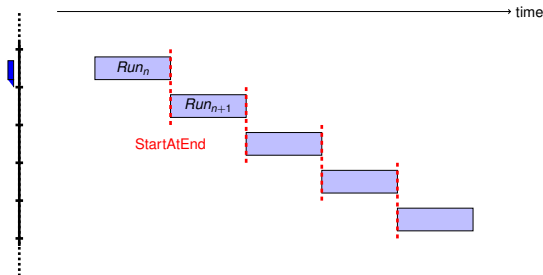
- Relations between intervals:
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 - Logical constraints

Optional Time-Interval Concept



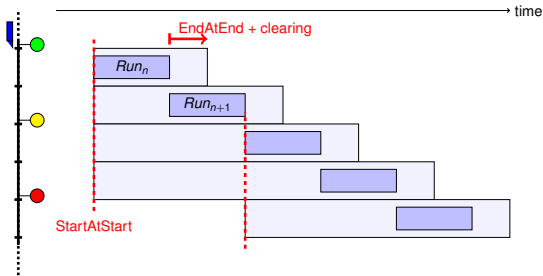
- Relations between intervals:
 - Temporal constraints \Rightarrow **Simple Temporal Network**
 - Logical constraints \Rightarrow **2-satisfiability Network**
 - **Propagation between both networks**

RECIFE-Intervals



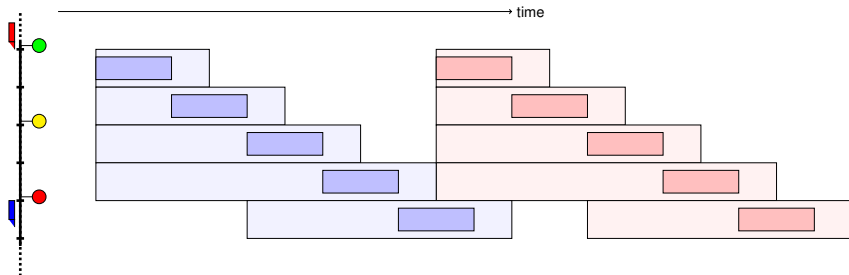
- "Run" Intervals
 - Running of the head of the train through the track detection sections

RECIFE-Intervals



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

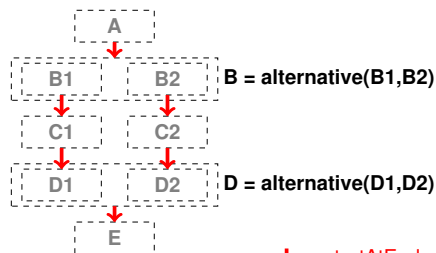
RECIFE-Intervals



- No overlapping of reservation intervals
⇒ Minimum spacing between trains

RECIFE-Intervals

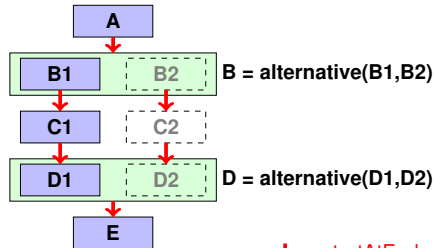
Alternative routes



↓ : startAtEnd + samePresence

RECIFE-Intervals

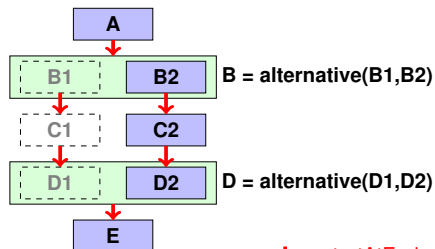
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RECIFE-Intervals

Alternative routes

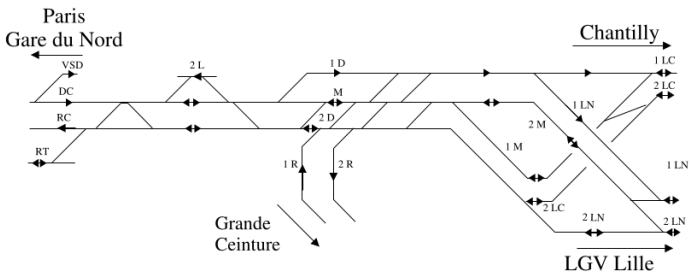


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Experiments

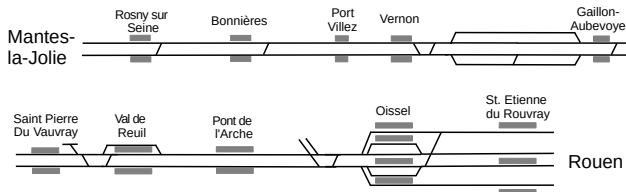
- Benchmark between **RECIFE-Intervals** and **RECIFE-MILP**  Pellegrini, P., Marlière, G., and Rodriguez, J. (2014)
 - Two-step approach :
 1. Limit of 10s CPU time : Fixed routes
 2. Limit of 180s CPU time : All route alternatives
- Horizon size variation :
 - **12 time intervals** : 10 mn to 120 mn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

Case studies #1



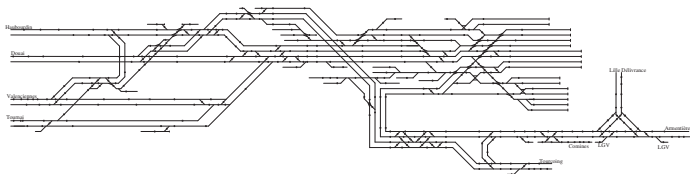
| Junction | | | Pierrefitte-Gonesse | | |
|-------------|--------------|----------------------|---------------------|----------|-----------|
| Length (km) | Routes | Blocks | Track Circuits | Stations | Platforms |
| 15 | 37 | 79 | 89 | 0 | 0 |
| Trains/Day | Routes/Train | Rolling stock roster | |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

Case studies #2



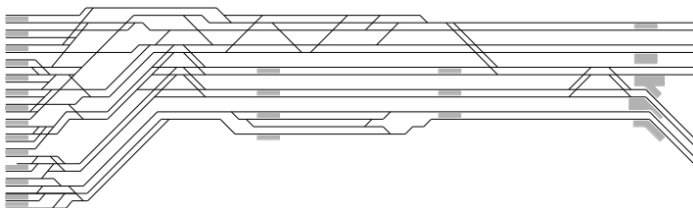
| Line | | | MLJ-Rouen | | |
|-------------|--------------|----------------------|----------------|-----------|-----------|
| Length (km) | Routes | Blocks | Track Circuits | Stations | Platforms |
| 80 | 187 | 157 | 236 | 13 | 23 |
| Trains/Day | Routes/Train | Rolling stock roster | | | |
| 237 | 1-24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

Case studies #3



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

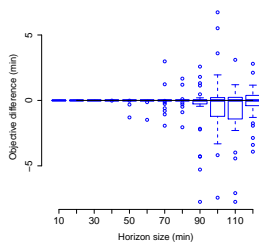
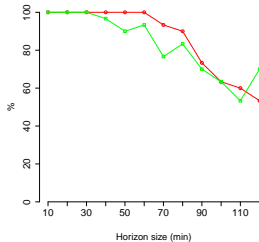
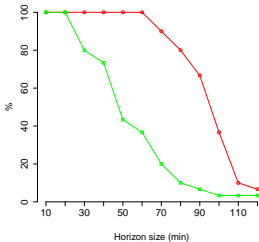
RECIFE-Intervals vs RECIFE-MILP

Proof of optimality

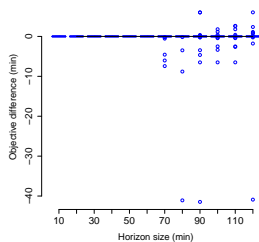
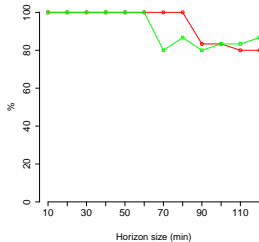
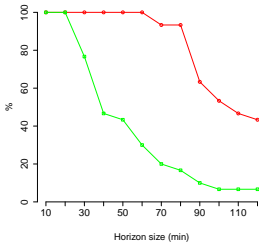
Best Solution

Objectif MILP - Intervals

#1 Gonesse



#2 MLJ-Rouen



Experimental Results

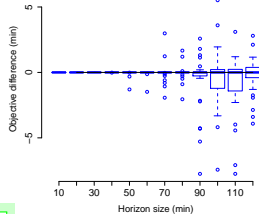
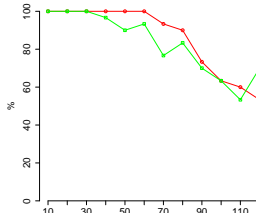
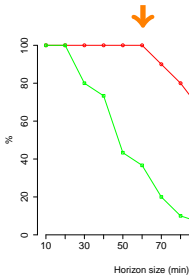
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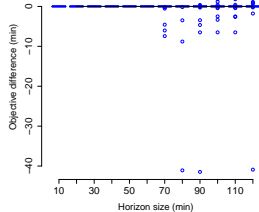
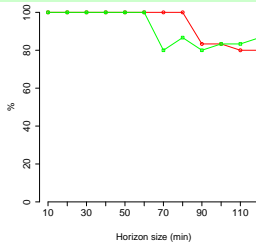
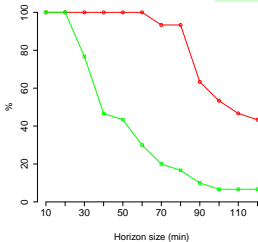
Objectif MILP - Intervals

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Less able to prove optimality

#2 MLJ-Rouen



Experimental Results

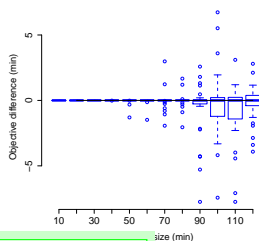
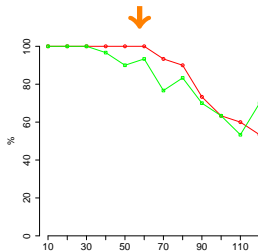
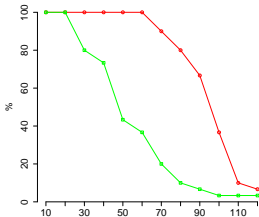
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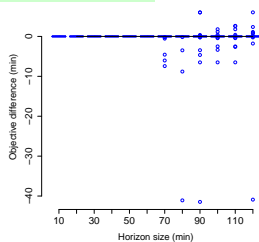
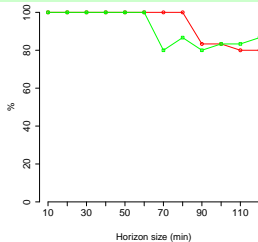
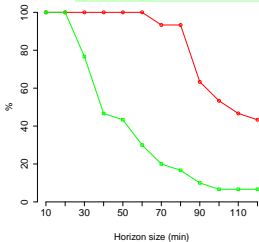
Objectif MILP - Intervals

#1 Gonesse



Some sub-optimal solutions on medium size instances

#2 MLJ-Rouen



Experimental Results

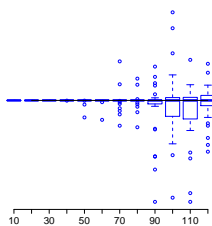
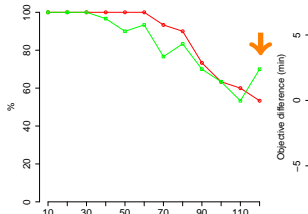
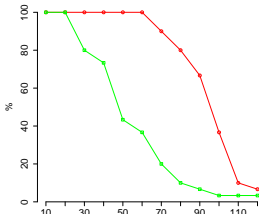
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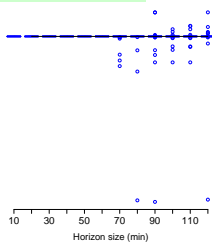
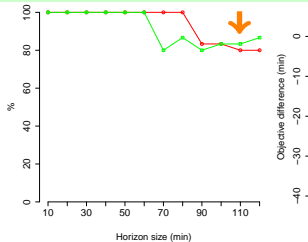
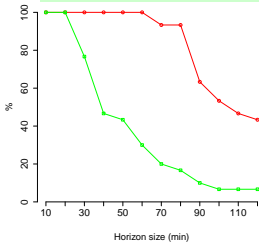
Objectif MILP - Intervals

#1 Gonesse



RECIFE-Intervals has better performances on large instances

#2 MLJ-Rouen



Experimental Results

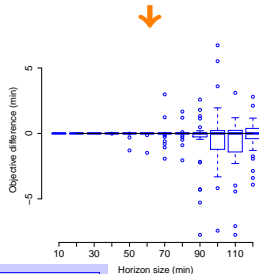
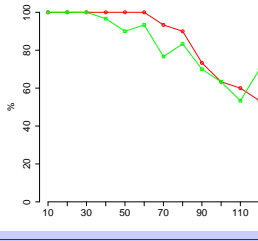
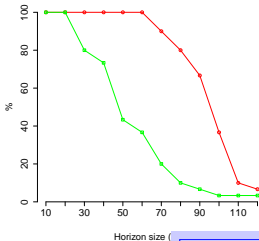
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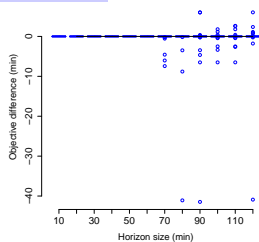
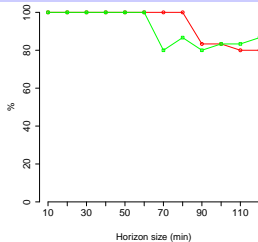
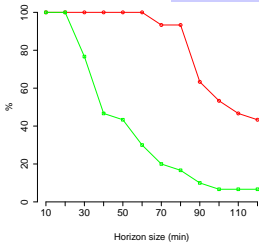
Objectif MILP - Intervals

#1 Gonesse



Few difference in terms of solution quality

#2 MLJ-Rouen



Experimental Results

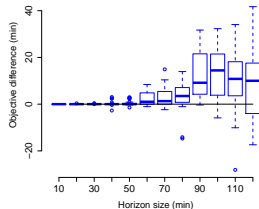
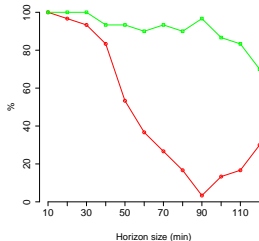
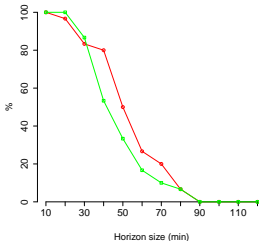
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Proof of optimality

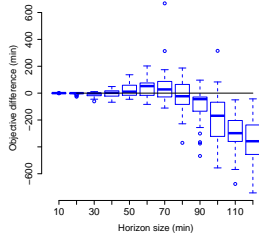
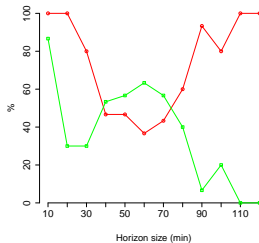
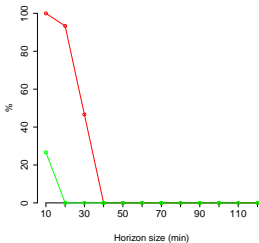
Best Solution

Objectif MILP - Intervals

#3 Lille



#4 Silazare



Experimental Results

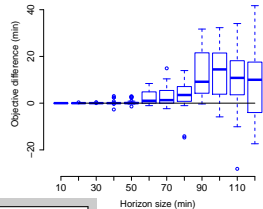
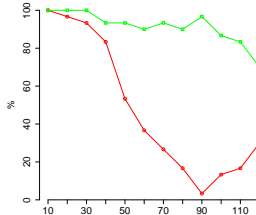
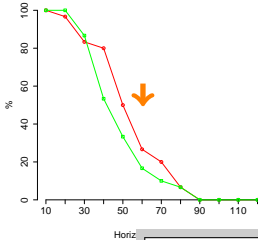
RECIFE-Intervals vs RECIFE-MILP

Proof of optimality

Best Solution

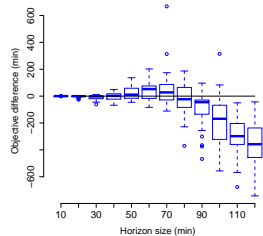
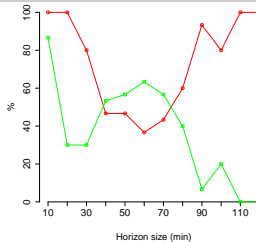
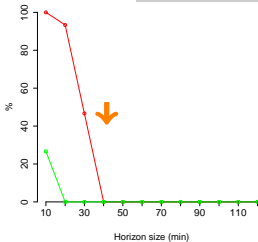
Objectif MILP - Intervals

#3 Lille



Difficult cases \Rightarrow optimality rarely proved

#4 Silazare



Experimental Results

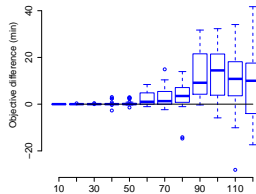
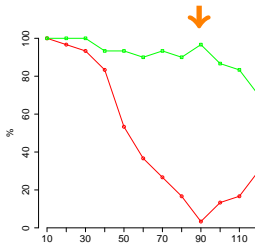
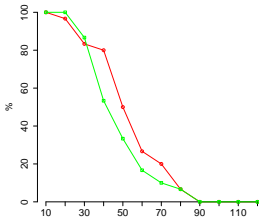
RECIFE-Intervals vs RECIFE-MILP

Proof of optimality

Best Solution

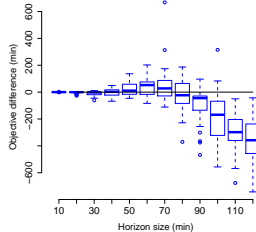
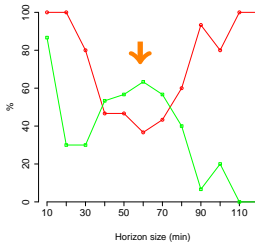
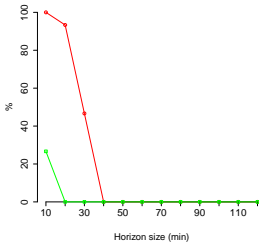
Objectif MILP - Intervals

#3 Lille



RECIFE-Intervals becomes more efficient on difficult instances

#4 Silazare



Experimental Results

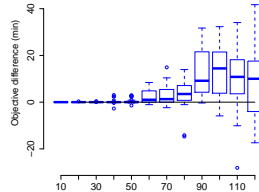
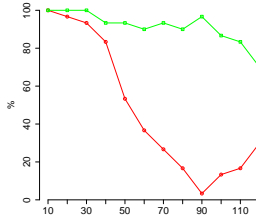
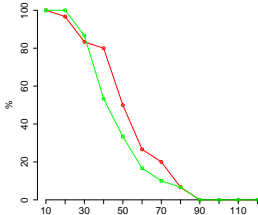
RECIFE-Intervals vs RECIFE-MILP

Proof of optimality

Best Solution

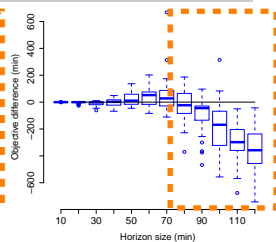
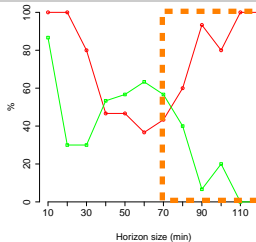
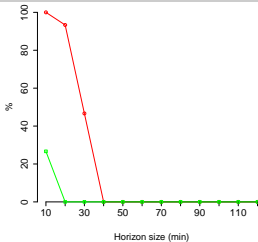
Objectif MILP - Intervals

#3 Lille



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

#4 Silazare



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