# FEEDFORWARD TACTICAL OPTIMIZATION FOR ENERGY EFFICIENT OPERATION OF FREIGHT TRAINS: THE SWISS CASE

Valerio De Martinis
Ambra Toletti
Francesco Corman
Ulrich A. Weidmann
Andrew Nash

Institut für Verkehrsplanung und Transportsysteme
Institute for Transport Planning and Systems

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  - Passenger trains vs Freight trains
  - The rail traffic in Switzerland
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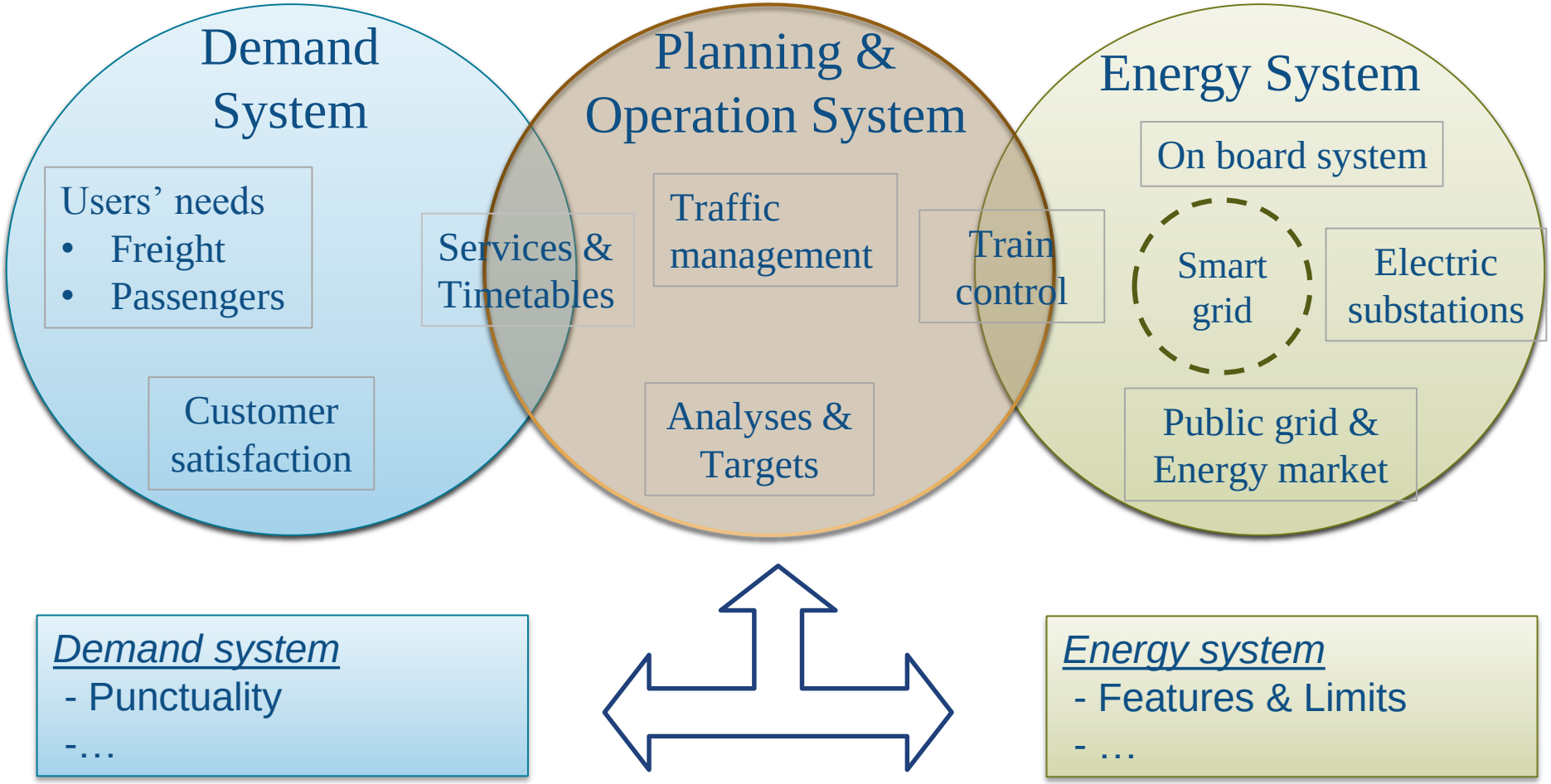
- Numerical experiment
- Conclusion

# Introduction

# Energy efficiency in railway operation



# Passenger trains vs Freight trains

VS

- Higher priority
- Higher punctuality
- Higher performances
- Defined timetable and routes
- Fixed composition
- …

Predefined models and operating conditions

- Lower priority
- Lower punctuality
- Lower performances
- Flexible departure times, stops, arrival times, routes
- Variable composition
- …

More subjected to rescheduling

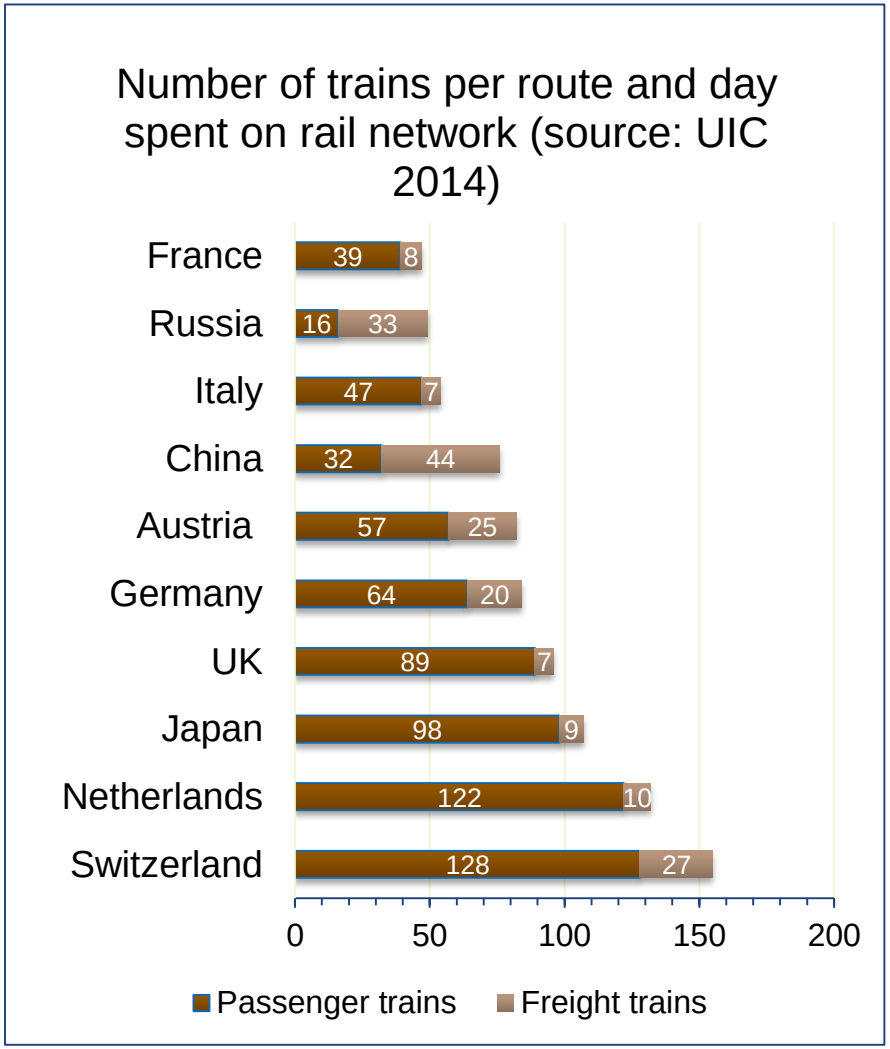
Predefined models may be unrealistic

Online procedures

# Rail operation data

We focus on energy efficiency in rail operation because:

- Rail traffic in Switzerland is the highest in the world (n. of trains per route)
- Freight rail traffic is a non negligible % of rail traffic in Switzerland (≈ 20%)
- Energy efficiency in rail operation contributes to the rail competitiveness.
- Energy efficient rail operation contributes to the transition phases (e.g. switching from conventional power sources to renewable ones)



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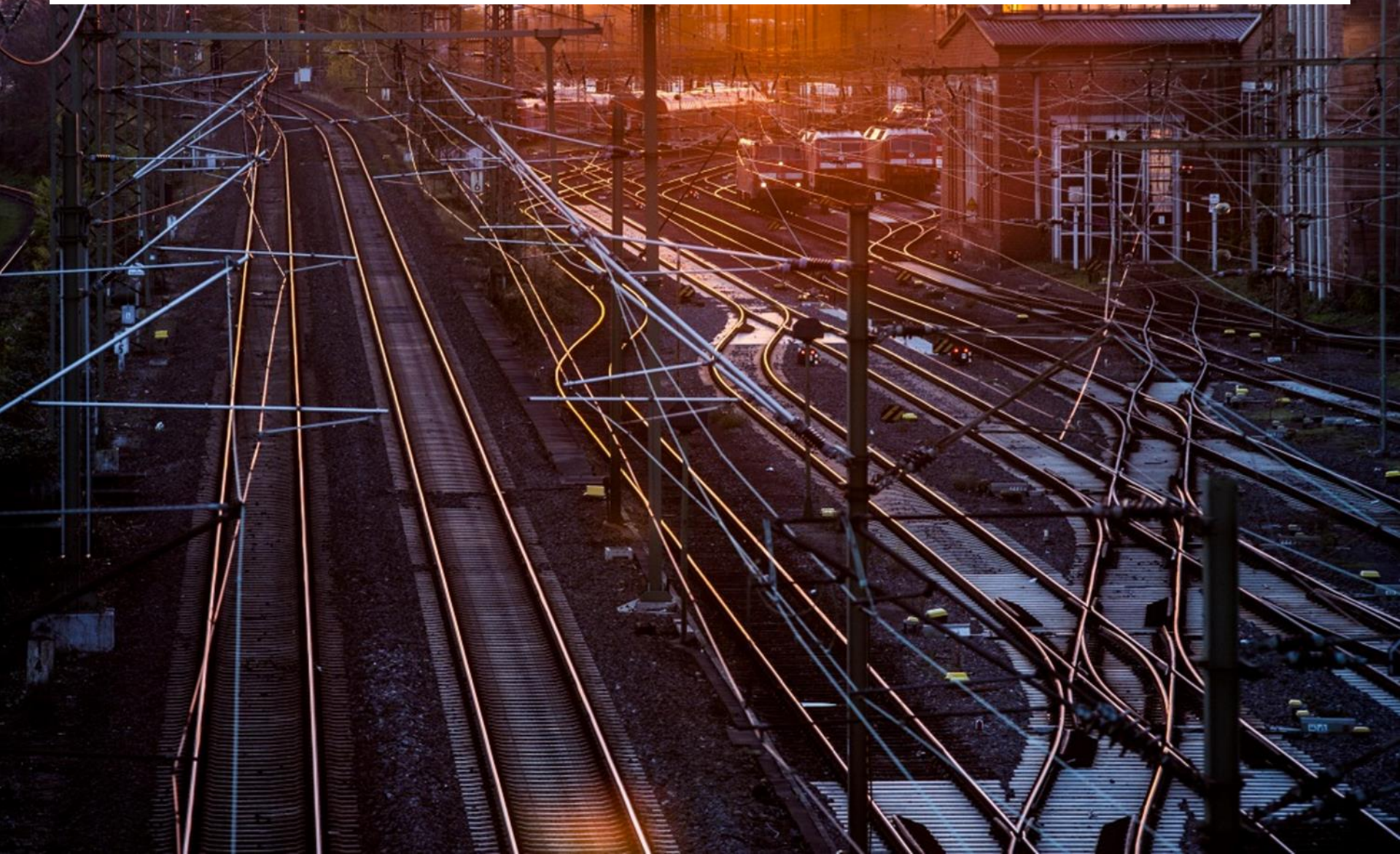
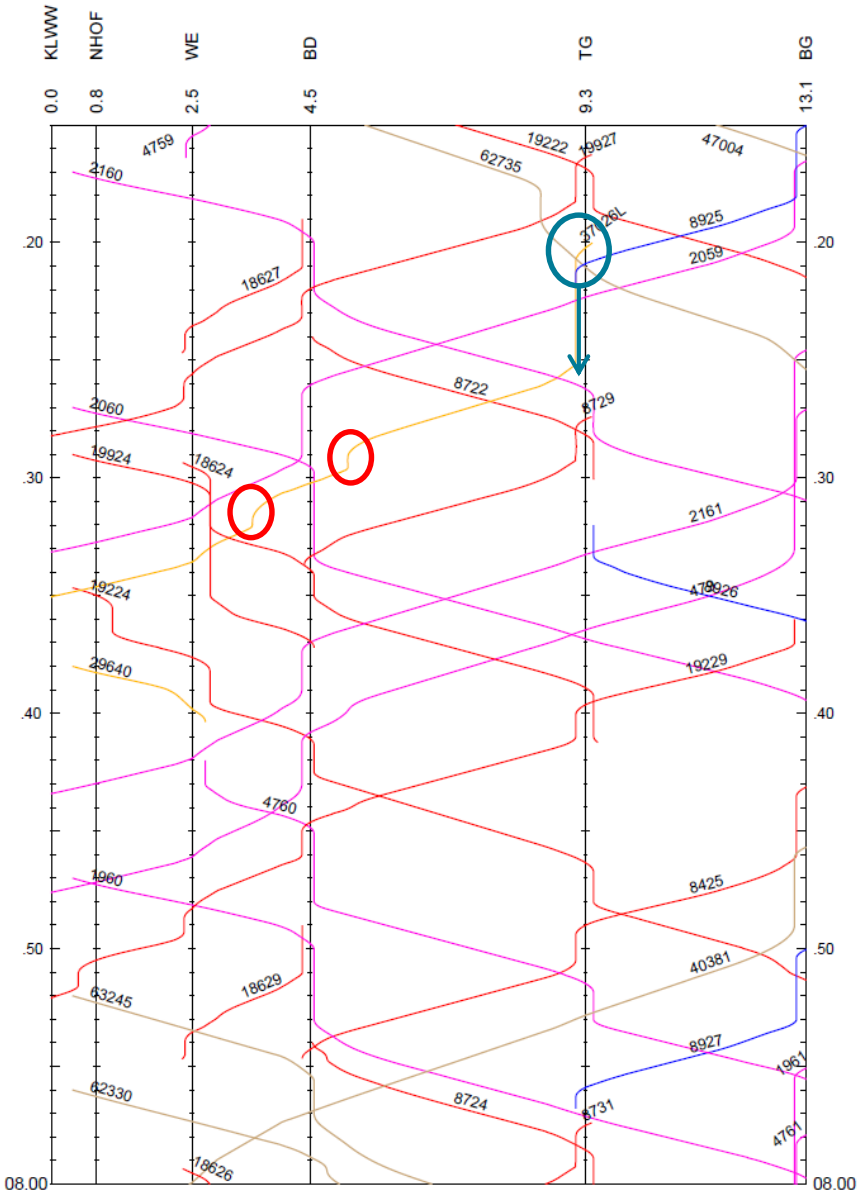
# Timetable vs. Real Operation



# Timetable

- Output of the planning process. Trade-off between:
  - Traffic demand and customers needs.
  - Rolling Stock & Infrastructures (RS&I) availability and characteristics.
- Travel times are based on RS&I characteristics
  - It fits passenger rail traffic
  - Freight trains have higher variation of performances.

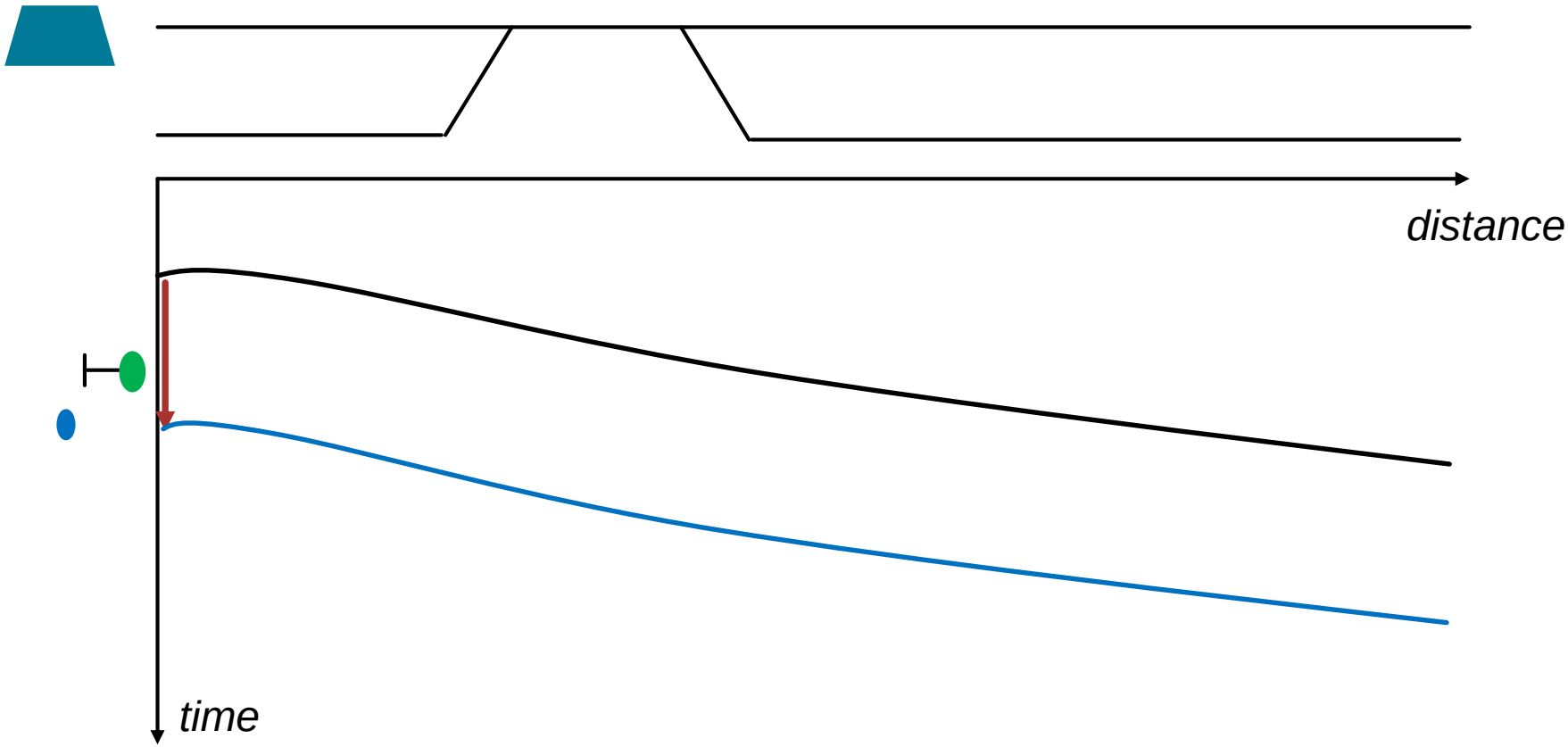


# Real Operation

- It is hard to accurately follow the timetable disposition.
- Delays and conflicts may arise.
- Modification of trains operation is often required. Use of rescheduling procedures and models.

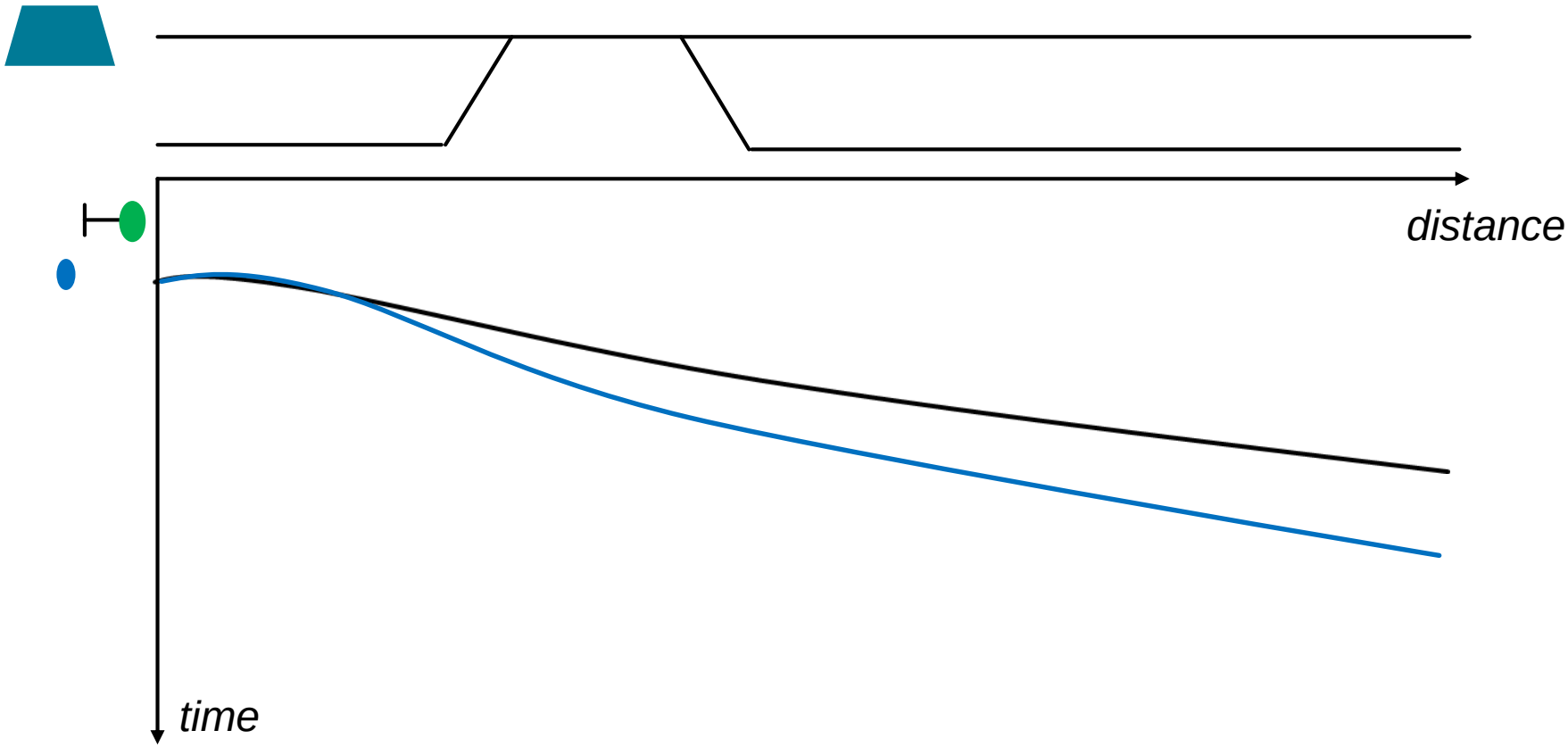
# Real operation

## Alternative departure times



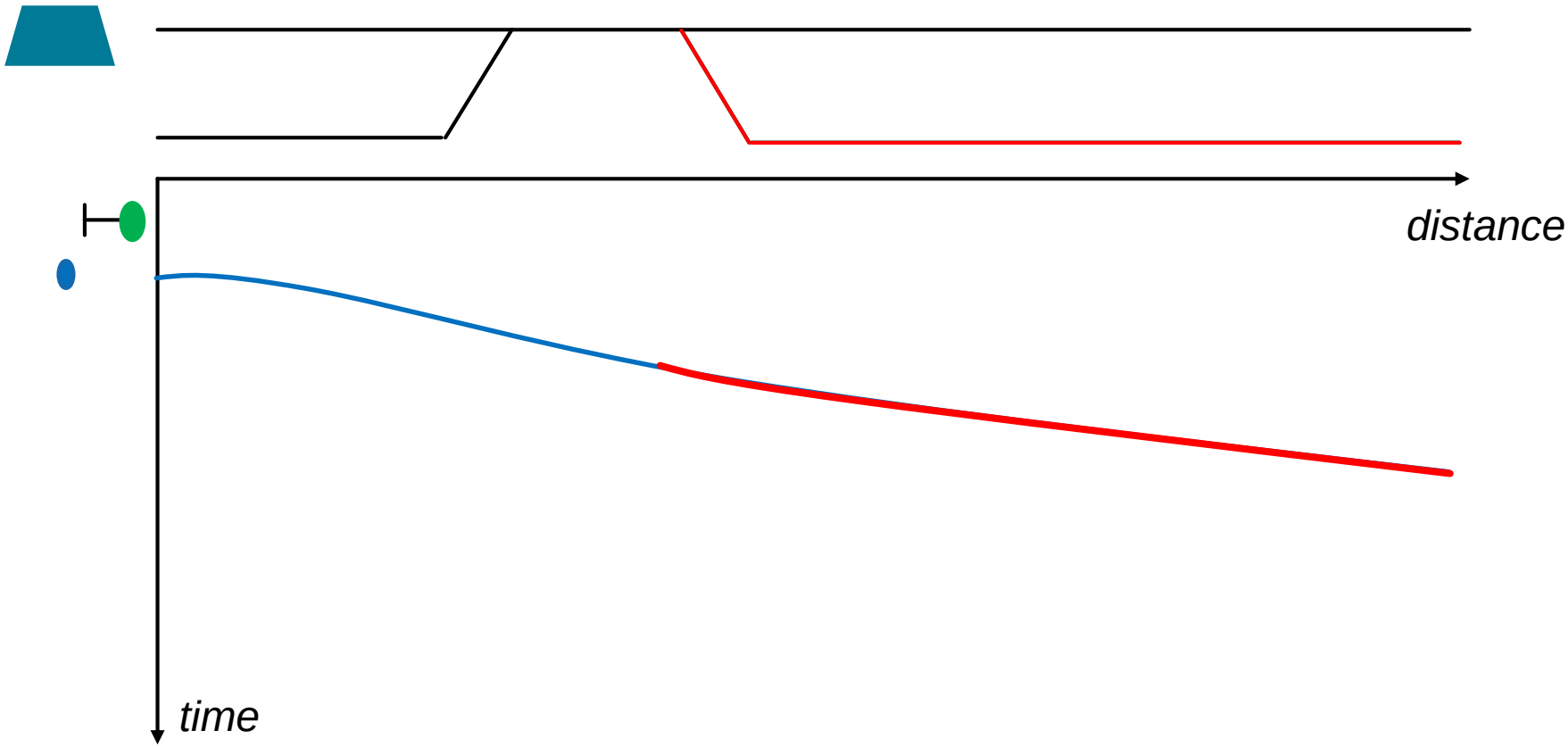
# Real operation

## Alternative speed profiles



# Real operation

## Alternative paths



# Real operation

- Being adherent to the timetable is very hard to achieve. Especially considering manual driving.
- Many modifications of train operation can generate consumptions higher than expected. The number of modifications should be the lowest possible.
- The main objective is still the minimization of delays.

Increase the degree of specification in the planning phase to reduce the gap between planned conditions and realized conditions.

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# Introducing Feed Forward Optimization

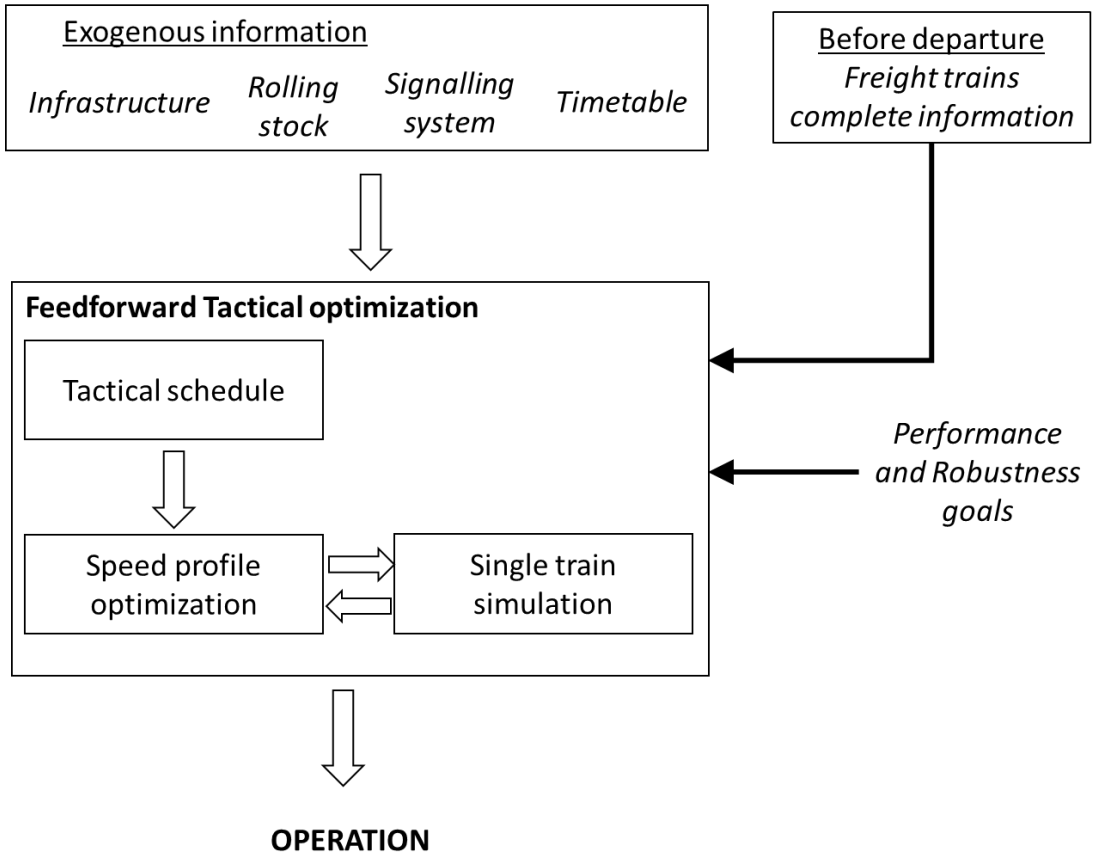
# Main idea

In some cases (e.g. SWL), real characteristics of freight trains (real departure, wagon composition, wagon disposition) are known only few hours before departure.

Within the departure decision and the real departure there is still time to possibly enhance the timetable for the specific train and its performances. How?

- Minimizing planned stops for traffic management (train overtaking)
- Generating energy saving speed profiles specifically for the given train.

# The framework



# Feedforward Tactical optimization

$$(T_{D1},\ldots,T_{Ai},T_{Di},\ldots,T_{Am})^{opt} = arg\min \sum_{i\in M} X_{Di}(T_{Ai},T_{Di})$$

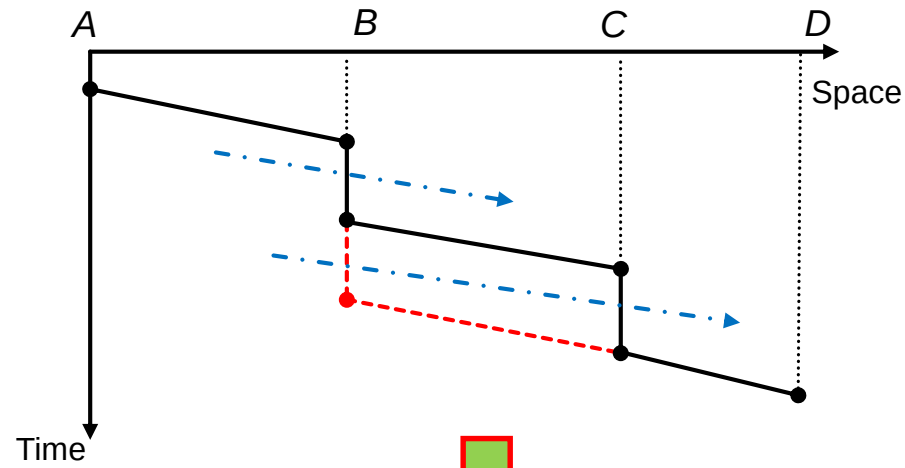
*Constraints*:

$$T_{Am} = \hat{T}_{Am}$$

$$T_{Di} \in \bigcup_j \left[\hat{\tau}_{Di}^{j} + MH_i(j,f), \hat{\tau}_{Di}^{j+1} - MH_i(f,j+1)\right] \quad \forall i \in M$$

$$T_{Ai} \le T_{Di} \quad \forall i \in M$$

$$T_{Ai} - T_{Di-1} = TT_{(i-1,i)} \quad \forall i \in M$$



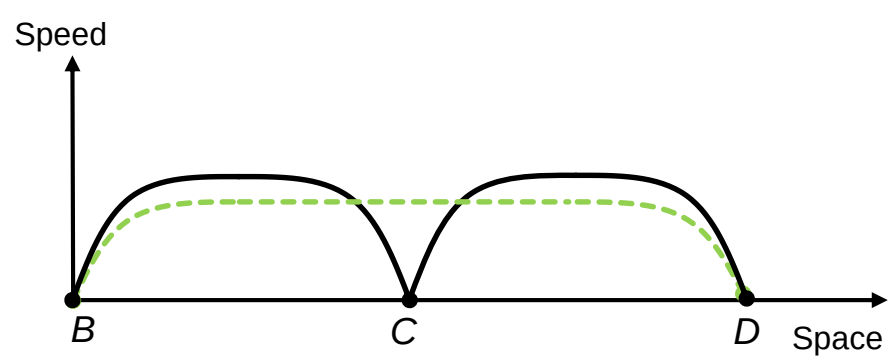

$$SP^{opt} = arg\min E(Sim(SP))$$

*Constraints*:

$$SP \le SP^{\max}$$

$$T(Sim(SP)) \le \hat{T}$$

$$S(Sim(SP)) = \hat{S}$$

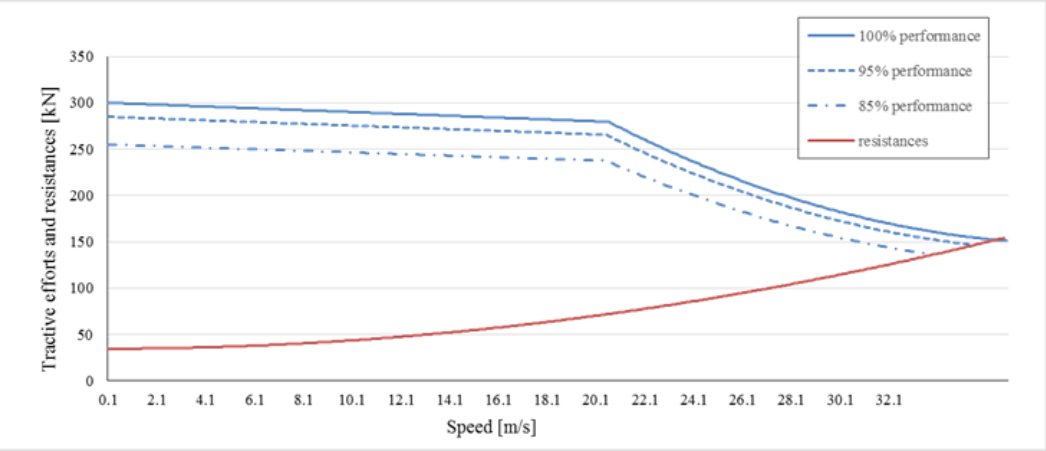


# Advantages

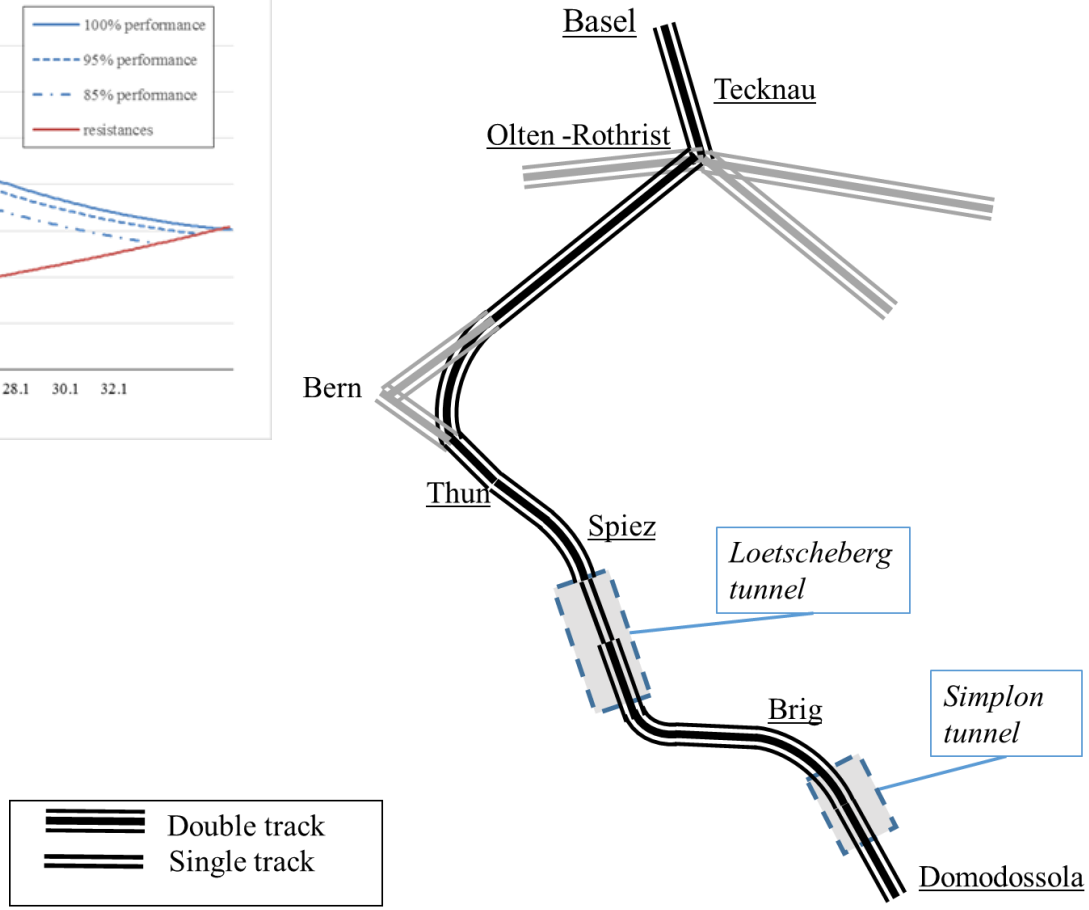
- Specific solutions for every train can be adopted.
- By avoiding stops, extra times previously spent for the braking and reaccelerating phases can be used to generate energy efficient speed profiles.
- Constraints on tactical optimization ensure that there is no trains conflict in the timetable.
- If the system will not find a solution (e.g. because of a very tight schedule), the original timetable will be adopted.

# Numerical experiment

# Data availability



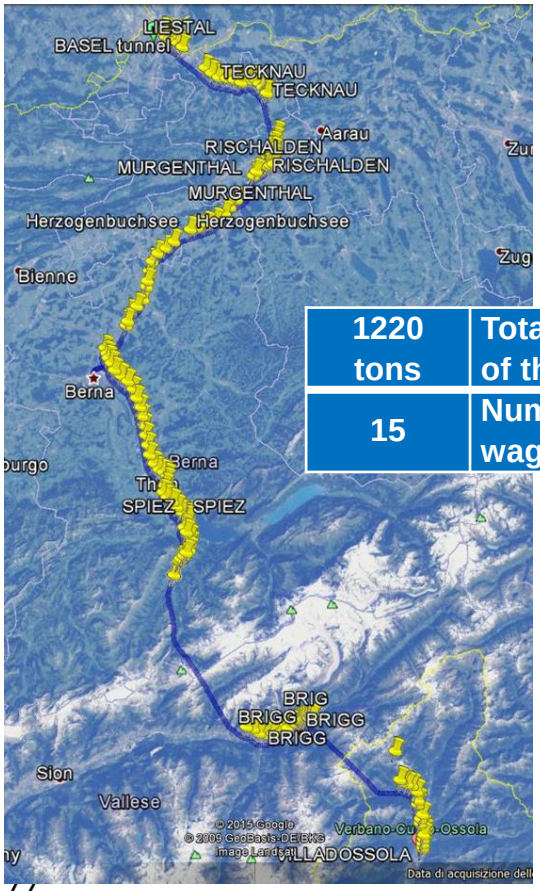

| BLS Re485 | Characteristics |
|---|---|
| 2002-2003 | Year |
| 84 tons | Weight |
| 87 mph (140km/h) | Max speed |
| 5.6 MW (7500 hp) | Power class |
| 18.9 m | Length |
| 300 kN | Tractive effort |
| 240 kN | Braking effort |



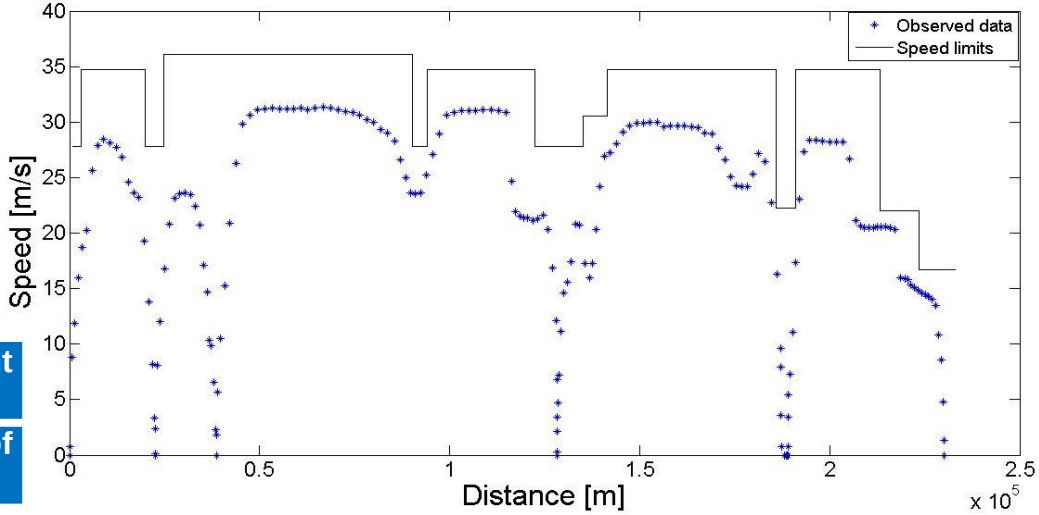

(*) Hans Waegli, “Bahnprofil Schweiz”, AS Verlag 2010

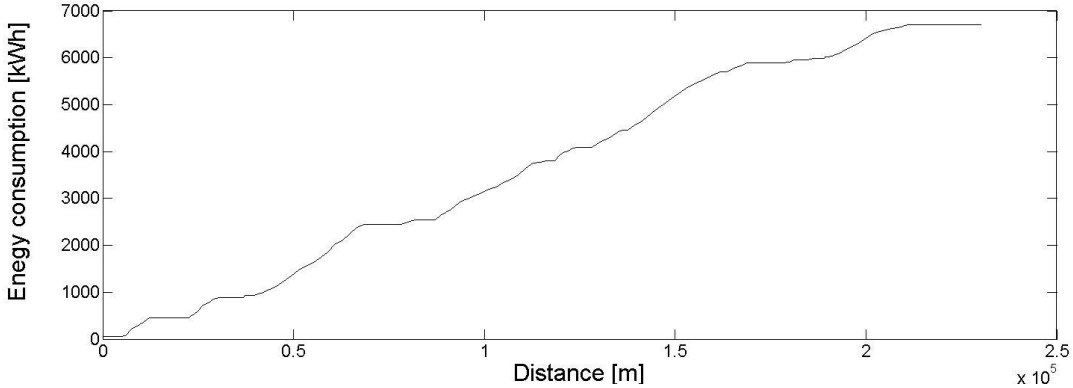
# Data availability

Onboard monitoring system (GPS, speed, energy consumed)

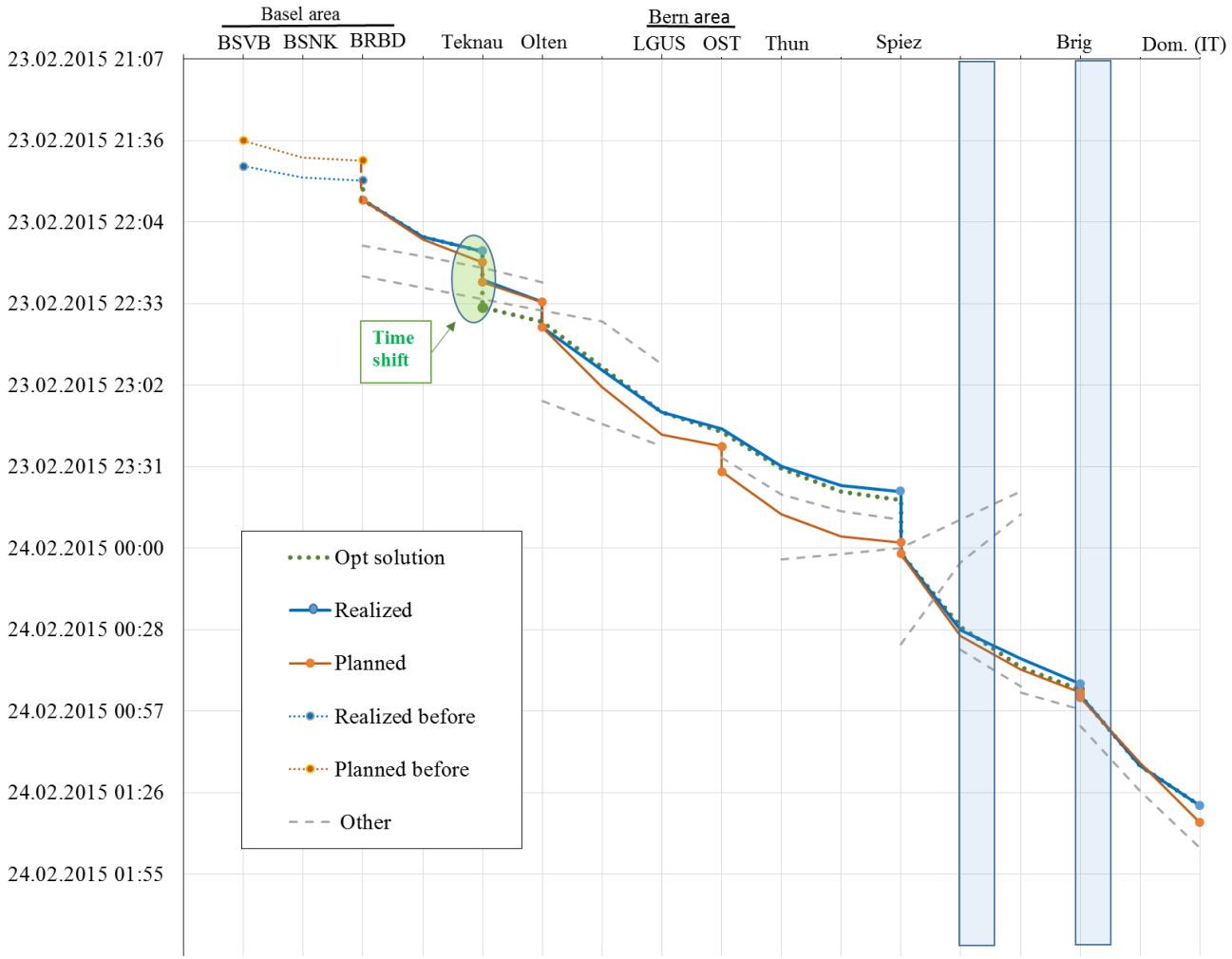



| | |
|---|---|
| 1220 tons | Total weight of the train |
| 15 | Number of wagons |



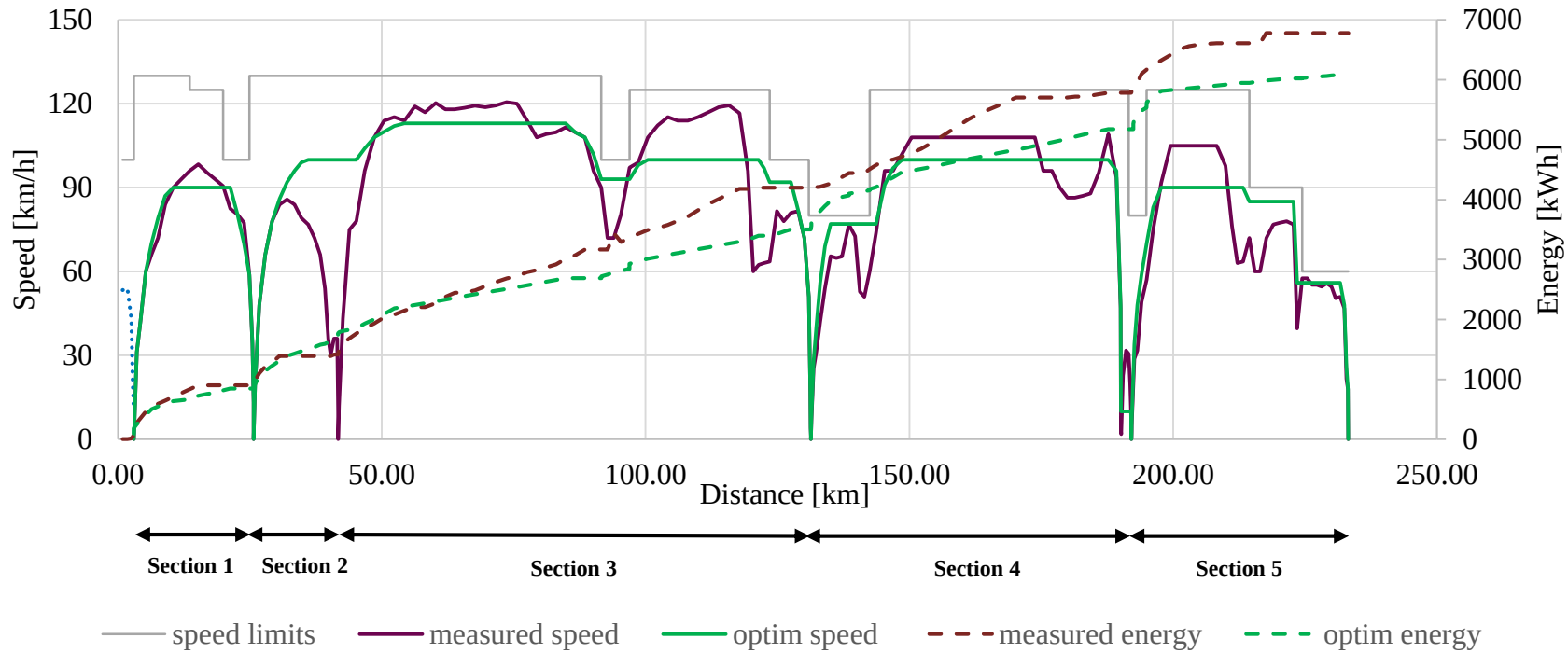



# Timetable and optimization hypothesis



# Speed profile optimization

Comparison between real data and energy saving (ES) results from optimization




| Energy | section 1 | section 2 | section 3 | section 4 | section 5 |
|---|---|---|---|---|---|
| measured [kWh] | 900 | 1412 | 4195 | 6014 | 6892 |
| optim [kWh] | 848 | (1724) | 3501 | 5174 | 6085 |
| **energy saved** | -5.78% | (22.10%) | -16.54% | -13.97% | -11.71% |

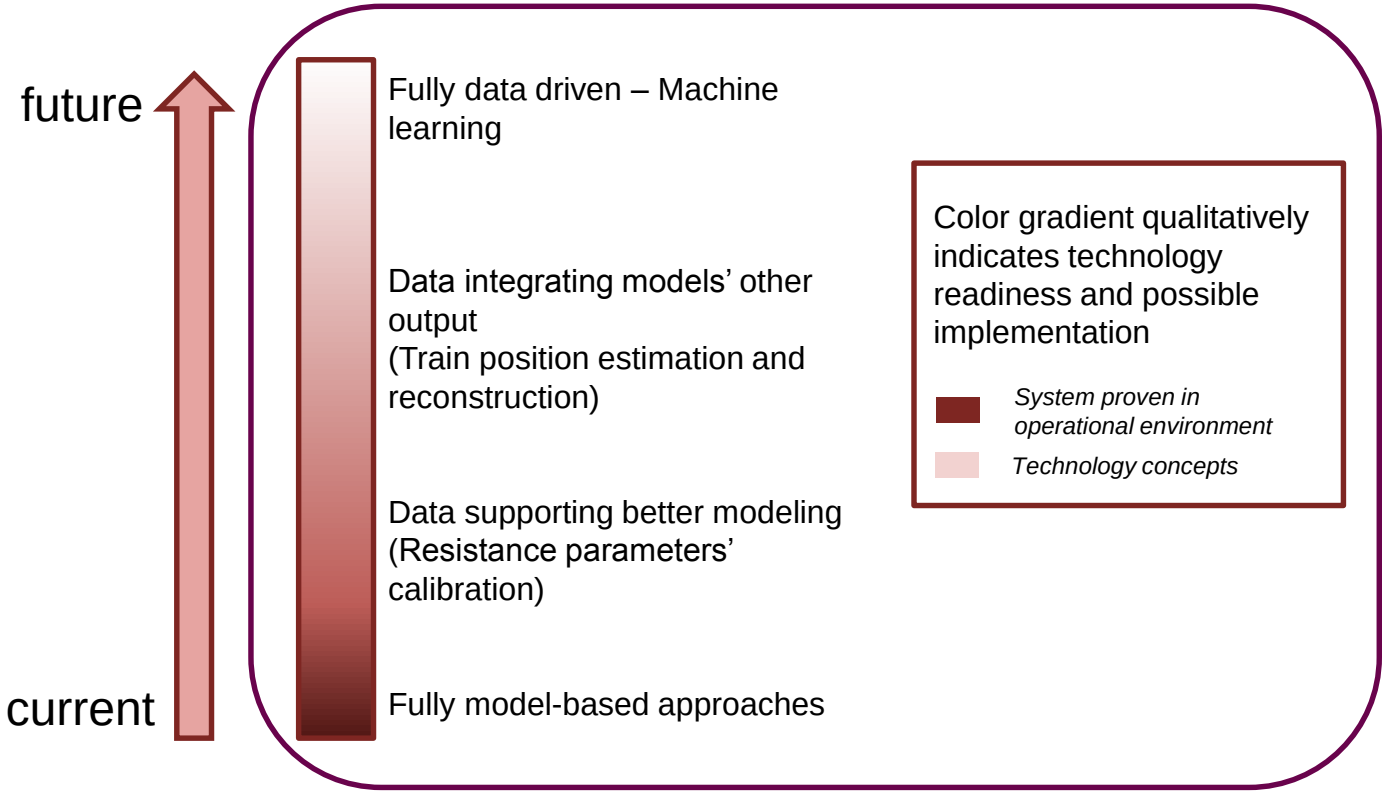
# Conclusions

# Other streams

- This experience highlighted how the variety of data collected can enrich and complete the required information. We are going towards the definition of data driven approaches (aka Big Data) for improving energy efficiency in rail operation.
- Our group have defined a possible scenario for the full deployment of energy consumption (and power used) data.

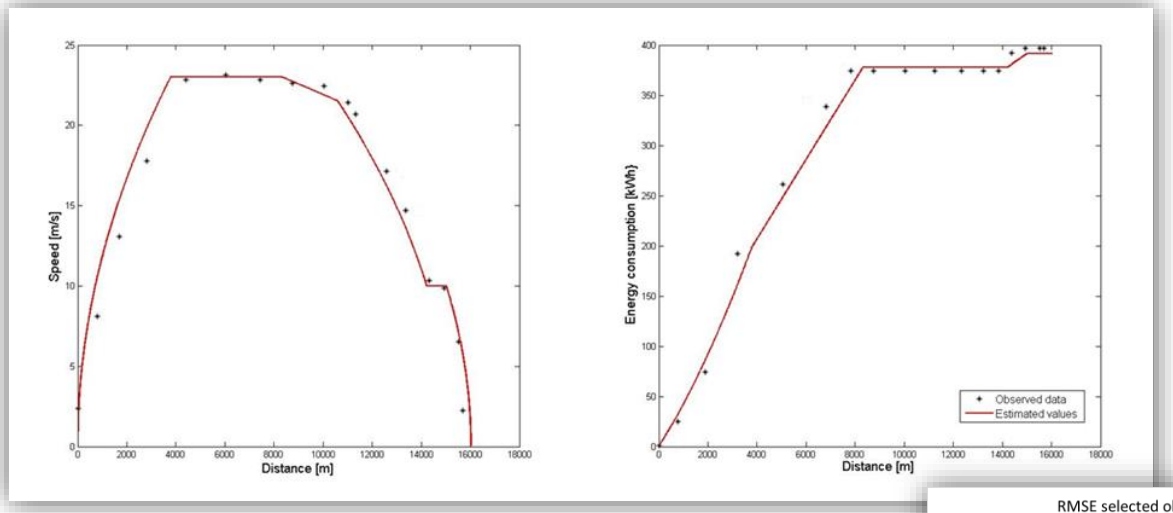
# Other streams

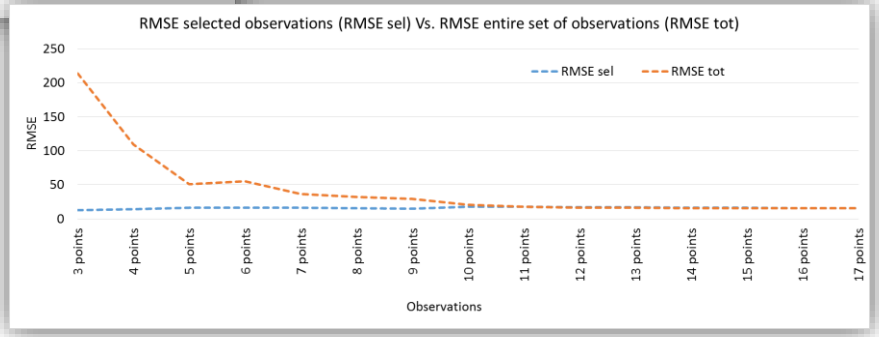
Data-driven perspectives on the use of energy consumption (and power used) data in railway systems



# Other streams

Resistance parameters' calibration



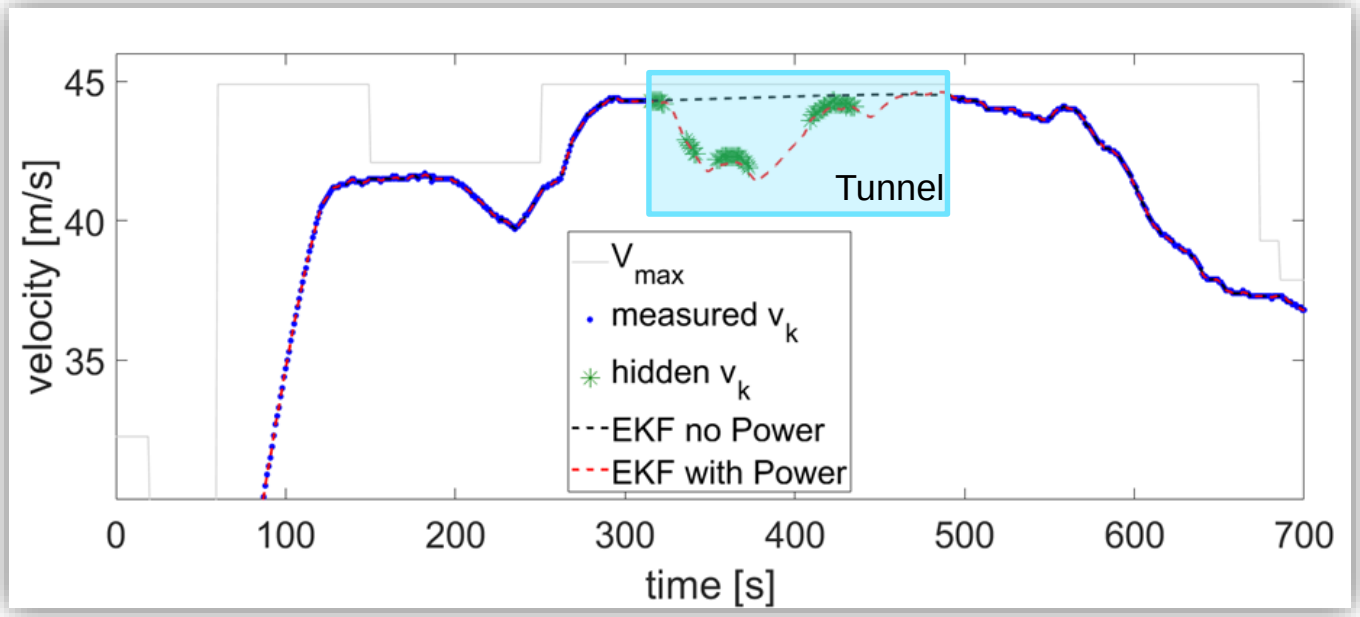




- First tempts with 1 min time step records
- Ongoing elaborations with 1 sec time step records

# Other streams

Train position estimation

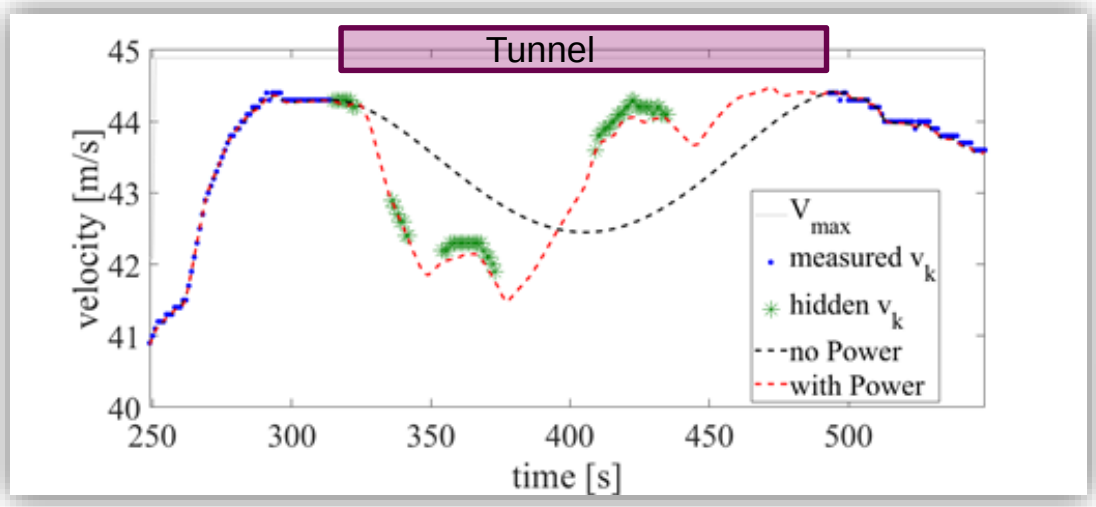
| | No Power | With Power |
|---|---|---|
| Comp_time [s] | 0.3220 | 0.3278 |
| Err_endTunnel [m] | 215.8 | 14.6 |

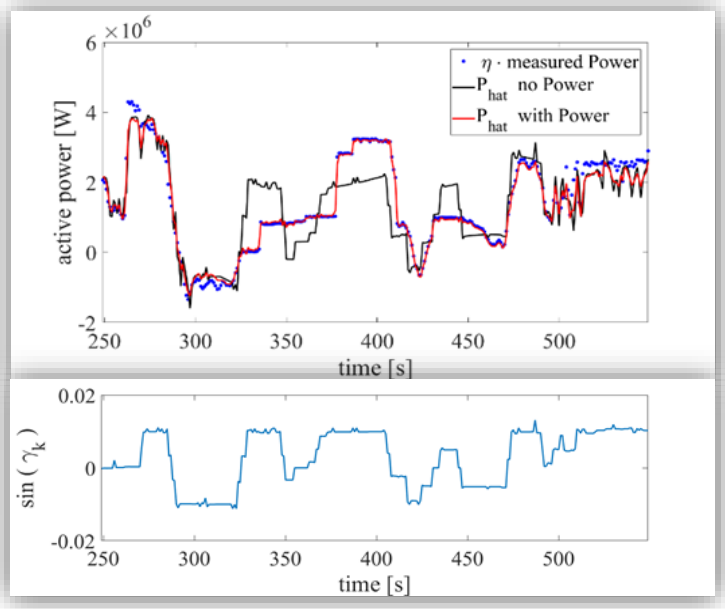



*Extended Kalman Filter with additional information on power used by the traction unit (onboard only measurements)*

# Other streams

Train trajectory reconstruction




*Maximum A Posteriori (MAP) with additional information on power used by the traction unit*

# Conclusions

- The model proposed allows to develop specific measures for increasing energy efficiency of freight trains.
- The model enhances when possible timetable dispositions and come closer to real-time traffic management.
- It is important to highlight that estimated energy savings refer to ideal driving conditions, which are difficult to approach without on-board Driving Assistance Systems or Automatic Train Operation (ATO).

→ In the future, for some demand-driven services this model may be applied also to passenger trains

# Future work

- Integration with delay management processes.
- Consider alternative methods to speed up the solution process (currently computing time is around 6 min)
- Tests on larger instances (more stations, more trains)
- The introduction of stop priorities.

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# Thank you for your kind attention!