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

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  - Energy efficiency in railway operation
  - Passenger trains vs Freight trains
  - The rail traffic in Switzerland
- Timetable vs. Real Operation
- Introducing Feed forward optimization
  - Tactical schedule
  - Energy efficient speed profiles
- Numerical experiment
- Conclusion
Introduction
Energy efficiency in railway operation

Demand System
- Users’ needs
  - Freight
  - Passengers
- Customer satisfaction

Planning & Operation System
- Traffic management
- Services & Timetables
- Analyses & Targets
- Train control

Energy System
- On board system
- Smart grid
- Electric substations
- Public grid & Energy market

**Demand system**
- Punctuality
- ...

**Energy system**
- Features & Limits
- ...

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Passenger trains vs Freight trains

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

Predefined models and operating conditions

VS

- 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

Predefined models and operating conditions
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)
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.
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

Exogenous information

Infrastructure  Rolling stock  Signalling system  Timetable

Feedforward Tactical optimization

Tactical schedule

Speed profile optimization  Single train simulation

Operation

Before departure

Freight trains complete information

Performance and Robustness goals
Feedforward Tactical optimization

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

Constraints:
\[ T_{Am} = \hat{T}_{Am} \]
\[ T_{Di} \in \bigcup_{j} \hat{\tau}_{Di}^j + MH_{i}(j, f), \hat{\tau}_{Di}^{j+1} - MH_{i}(f, j+1) \quad \forall i \in M \]
\[ T_{Ai} \leq T_{Di} \quad \forall i \in M \]
\[ T_{Ai} - T_{Di-1} = TT_{(i-1,i)} \quad \forall i \in M \]

\[ SP^{opt} = \arg \min E(\text{Sim}(SP)) \]

Constraints:
\[ SP \leq SP^{\text{max}} \]
\[ T(\text{Sim}(SP)) \leq \hat{T} \]
\[ S(\text{Sim}(SP)) = \hat{S} \]
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

<table>
<thead>
<tr>
<th>BLS Re485</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002-2003</td>
<td>Year</td>
</tr>
<tr>
<td>84 tons</td>
<td>Weight</td>
</tr>
<tr>
<td>87 mph (140km/h)</td>
<td>Max speed</td>
</tr>
<tr>
<td>5.6 MW (7500 hp)</td>
<td>Power class</td>
</tr>
<tr>
<td>18.9 m</td>
<td>Length</td>
</tr>
<tr>
<td>300 kN</td>
<td>Tractive effort</td>
</tr>
<tr>
<td>240 kN</td>
<td>Braking effort</td>
</tr>
</tbody>
</table>

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

Onboard monitoring system (GPS, speed, energy consumed)

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

Diagram showing speed and energy consumption over distance.
Timetable and optimization hypothesis
Speed profile optimization

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

<table>
<thead>
<tr>
<th>Energy</th>
<th>section 1</th>
<th>section 2</th>
<th>section 3</th>
<th>section 4</th>
<th>section 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>measured [kWh]</td>
<td>900</td>
<td>1412</td>
<td>4195</td>
<td>6014</td>
<td>6892</td>
</tr>
<tr>
<td>optim [kWh]</td>
<td>848</td>
<td>(1724)</td>
<td>3501</td>
<td>5174</td>
<td>6085</td>
</tr>
<tr>
<td>energy saved</td>
<td>-5.78%</td>
<td>(22.10%)</td>
<td>-16.54%</td>
<td>-13.97%</td>
<td>-11.71%</td>
</tr>
</tbody>
</table>
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

Future

Fully data driven – Machine learning

Data integrating models’ other output (Train position estimation and reconstruction)

Data supporting better modeling (Resistance parameters’ calibration)

Current

Fully model-based approaches

Color gradient qualitatively indicates technology readiness and possible implementation

System proven in operational environment
Technology concepts
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

<table>
<thead>
<tr>
<th></th>
<th>No Power</th>
<th>With Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp_time [s]</td>
<td>0.3220</td>
<td>0.3278</td>
</tr>
<tr>
<td>Err_endTunnel [m]</td>
<td>215.8</td>
<td>14.6</td>
</tr>
</tbody>
</table>

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!