Impacts on railway operations of the ETCS level 3: models and application to the Napoli-Sorrento railway

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Background

• **Increasingly high level of technology** involved in train operation under ERTMS ETCS level 3 (e.g. EVC, RBC, position balises)

• **Existing micro-simulation software do not account** for such technology

  e.g.
  
  ▪ *purely kinematic* braking model
  ▪ *uncompensated* gradient profile
  ▪ *un-modeled* reaction time in speed profile calculation (by EVC)
  ▪ *un-modeled* information communication technology (e.g. delays)

• **Assessment** of new technologies (e.g. GPS tracking, virtual balises) or new operation strategies (e.g. eco-driving) **is hindered**
Motivations and Objective

• Accurate *speed profiles*
  → Evaluation of energy consumptions
  → Energy recovery / energy saving
  → Design of eco-driving speed profiles

• Reliable quantification of *system performances*
  → Technology requirements for different signaling systems
  → Robust timetable design (e.g. stochastic processes)
  → Real-time system optimization (e.g. re-scheduling)

A unified modeling framework to accurately reproduce the impact of all ETCS technologies involved in railway operation
A Model Predictive Control (MPC) with rolling horizon calculates the speed command to execute according to the information on EOA.

Information on EOA available at $t$ is delayed $x_{EOA}^{Avail}(t) = x_{EOA}(t - \text{delay})$.

The MPC plans the speed value to execute at time $t + RT + \Delta t_{SIM}$ given the constraints set by the signaling and interlocking systems, the infrastructure, the rolling stock, the passengers’ comfort and the electrical power available.
ATO model

Optimal control problem solution

Solution is not unique
Feasibility domain includes different speed values all compatible with constraints; the solution depends on the driving strategy undertaken by the train

The solution consists in the selection of one of the following strategies:

1. acceleration
2. cruising
3. braking

Selected strategy is the first one that allows to reach the higher speed value and that is compatible with all constraints
ATM model

Driving strategy selection

subject to contains on:

EOA \[ x(t + RT) + \int_{t + RT}^{t\text{ at stop}} v(t) \cdot dt \leq x_{EAO}^\text{Avail.}(t) \]

Kinematics (e.g. \( a_{Max} \), \( d_{Max} \), \( j_{Max} \), \( j_{Min} \))

Infrastructure (e.g. max oper. speed, overlapping)

Rolling stock (e.g. max speed, engine, braking)

Energy supply (e.g. available power)
Modeling Framework

Innovation

- Speed profiles with kinematic constraints on acceleration and jerk → Reproduction of speed transitions
- Numerical integration of ERA braking curves → Accounts for resistances and adhesion
- Consistency with ERTMS ETCS standards → Gradient compensation with train length → Signal delays → On-board computing time of EVC and driver reaction time
- Common modeling framework for ETCS levels 1 to 3 (+ soft wall & national systems, e.g. BACC in Italy)
### Applications

**Impacts of ETCS tech on double-track railway**

*(Cumana line, Naples)*

<table>
<thead>
<tr>
<th>ETCS Level</th>
<th>Headway minimo [sec]</th>
<th>Capacità [veh/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>349</td>
<td>10.3</td>
</tr>
<tr>
<td>2</td>
<td>270</td>
<td>13.4</td>
</tr>
<tr>
<td>3 (Hard Wall)</td>
<td>129</td>
<td>27.9</td>
</tr>
<tr>
<td>3 (Soft Wall)</td>
<td>122</td>
<td>29.5</td>
</tr>
</tbody>
</table>

- **Increasing capacity** moving from level 1 to level 3
- ETCS level 3 produces a **greater marginal increase** of capacity
  (100% from level 2 to 3 vs. 30% from level 1 to 2)
## Applications

**Impacts of ETCS tech on single-track railway**

*(Naples-Sorrento line, EAV)*

**Methodology:** Global Sensitivity Analysis using *‘Variance-based’ quasi-Monte Carlo methods* (low discrepancy sequences i.e. Sobol sequence)

### Uncertain input factors [range]

1. Train departure headway \([10,45]\) min
2. Signalling update delay \([5,15]\) s
3. Signalling update frequency \([1,10]\) s
4. Reaction time \([10,20]\) s
5. Virtual balise spacing \([100,2500]\) m
6. Spatial error on balise localization \([10,30]\) m
7. Train departure time offset on opposite directions \([0,30]\) min

### Uncertain outputs

1. Travel times per route
2. Average delay at stations
3. Number of departed trains
4. Number of arrived trains
Applications

Average delay at stations
Applications

*Sensitivity indices on average delay at stations*

First-order and Total Sensitivity Indices - RouteD1 DelayAverage[s]

- **Total Sensitivity Index (ST)**
- **First Order Sensitivity Index (S)**

- ST: 90% confidence interval
- S: 90% confidence interval
Applications

*Impacts of ETCS tech on single-track railway*  
* (Naples-Sorrento line, EAV)

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<tr>
<th>ETCS Level</th>
<th>Headway minimo [min]</th>
<th>Capacità [veh/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BACC</td>
<td>12.7</td>
<td>4.7</td>
</tr>
<tr>
<td>3 (Soft Wall)</td>
<td>11.4</td>
<td>5.2</td>
</tr>
</tbody>
</table>

- Capacity increase is **marginal**  
- **Interlocking** in single-track railway is the major influencing factor on capacity
Conclusions

- **Accurate modeling** of ETCS technology is **crucial** for assessment.
- A unified modeling framework for ATO and signaling systems overcomes limitations of existing models.
- ETCS level 3 produces the **increase of capacity** in double-track railway.
- ETCS technology in **single-track railway has a minor impact** on delays.
- **Interlocking management** is the major factor influencing capacity in single-track railway.
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