Optimizing train trajectories for energy consumption using a traction- and speed-dependent engine efficiency

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1. Optimization problem
2. Dynamic programming
3. Comparing energy efficient train trajectories
4. Results and challenges
1 Optimization problem

\[ \dot{x} = \left( \frac{F_{B,\text{max}}}{m} u(t, x_2) - \frac{x_2}{m} F_W(x_2) - F_S(x_1) \right) \]  

\[ J = E = F_{B,\text{max}} \int_0^{t_F} \frac{1}{2 \eta} (u + |u|) x_2 \, dt \rightarrow \min \]

**Diagram:**
- **Speed**
  - \( v_{\text{max}} \)
- **Distance**
  - Accelerating
  - Cruising
  - Coasting
  - Braking

**Key Terms:**
- E: energy
- \( F_{B,\text{max}} \): max. braking force
- \( F_S \): line resistance force
- \( F_W \): driving resistance force
- m: mass
- t: time
- \( t_F \): travel time
- u: control variable
- \( x_1 \): distance
- \( x_2 \): speed
- \( \eta \): efficiency
1 Optimization problem

\[
\dot{x} = \left( \frac{F_{B,\text{max}}}{m} u(t, x_2) - \frac{x_2}{m} F_W(x_2) - F_S(x_1) \right)
\]

\[
J = E = F_{B,\text{max}} \int_0^{t_F} \frac{1}{2} \frac{1}{\eta(u, x_2)} (u + |u|) x_2 \, dt \rightarrow \min
\]
1 Optimization problem

\[ \dot{x} = \left( \frac{F_{B,\text{max}}}{m} u(t, x_2) - \frac{x_2}{m} F_{W}(x_2) - F_{S}(x_1) \right) \] (2a)

\[ J = E = F_{B,\text{max}} \int_{0}^{t_F} \frac{1}{\eta(u, x_2)} ((u + |u|)x_2 \, dt \to \min \] (2b)
2 Dynamic programming
3 Comparison (flat scenario)

Energy efficient train trajectory (Trajectory I) assuming constant losses in the propulsion system (distance: 7.5 km, travel time: 400 s)
Energy efficient train trajectory (Trajectory II) assuming variable losses in the propulsion system (distance: 7.5 km, travel time: 400 s)
Comparison of Trajectory I (constant losses) and II (variable losses)
(distance: 7.5 km, travel time: 400 s)
3 Comparison (mountainous scenario)
3 Comparison (mountainous scenario)

Comparison of Trajectory I (constant losses) and II (variable losses)
(distance: 18 km, travel time: 11 to 15 min)
Computed energy consumption and energy saving potential in relation to the available travel time reserve (distance: 18 km, travel time: 11 to 15 min, mountainous scenario)
4 Results and challenges

Achievements

• consideration of power losses in the propulsion system constitute a crucial enhancement to the train model

• up to 6% energy saving potential compared to the previous optimization approach

• differences between the obtained trajectories are especially prominent during phases of high speed

Challenges

• put into practice (driver training courses, DAS, ...)

• reduce computational time, allow a real time application

• enhance driving comfort