



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

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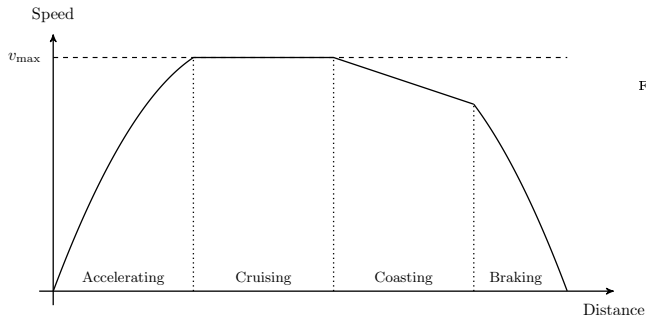
Optimizing train trajectories for energy consumption using a traction- and speed-dependent engine efficiency

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

1 Optimization problem

$$\dot{\mathbf{x}} = \begin{pmatrix} \frac{F_{B,\max}}{m} u(t, x_2) - \frac{1}{m} F_W(x_2) - F_S(x_1) \\ x_2 \end{pmatrix} \quad (2a)$$

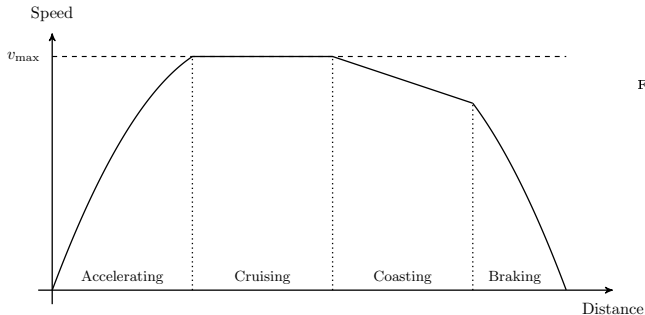
$$J = E = F_{B,\max} \int_0^{t_F} \frac{1}{2} \frac{1}{\eta} (u + |u|) x_2 dt \rightarrow \min \quad (2b)$$



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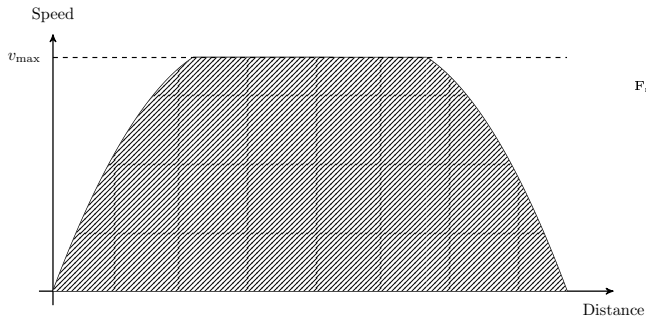


E ..energy
 $F_{B,\max}$..max. braking force
 F_S ..line resistance force
 F_W ..driving resistance force
 m ..mass
 t ..time
 t_F ..travel time
 u ..control variable
 x_1 ..distance
 x_2 ..speed
 η ..efficiency

1 Optimization problem

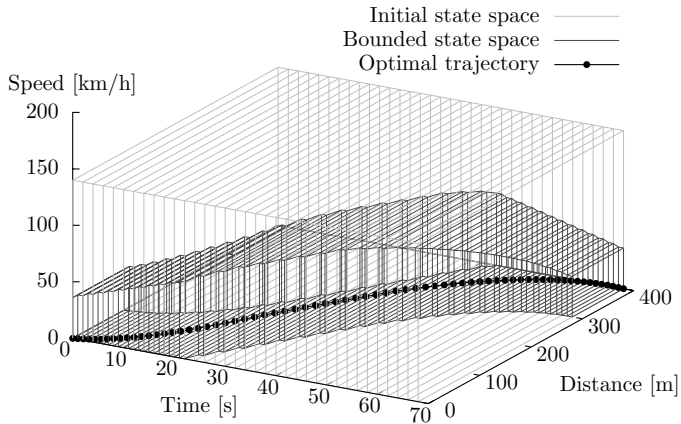
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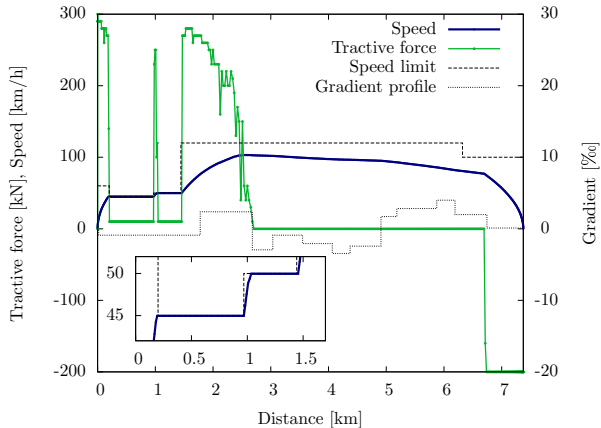


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2 Dynamic programming

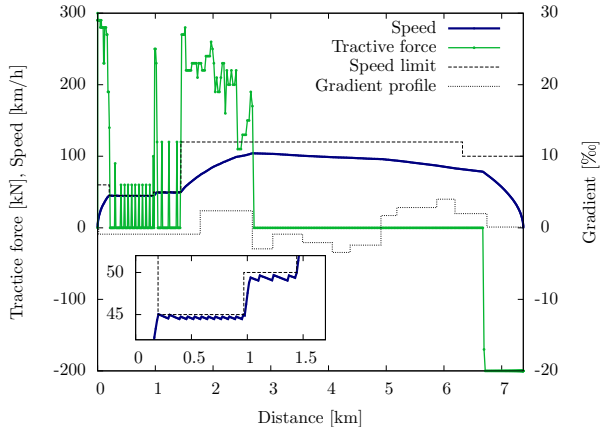


3 Comparison (flat scenario)

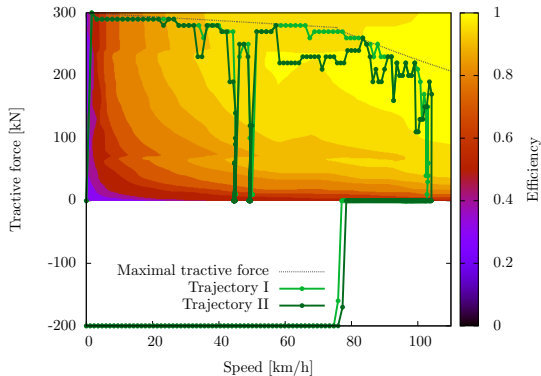
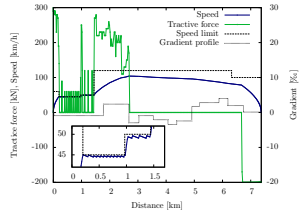
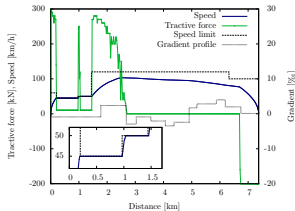


Energy efficient train trajectory (Trajectory I) assuming constant losses in the propulsion system (distance: 7.5 km, travel time: 400 s)

3 Comparison (flat scenario)

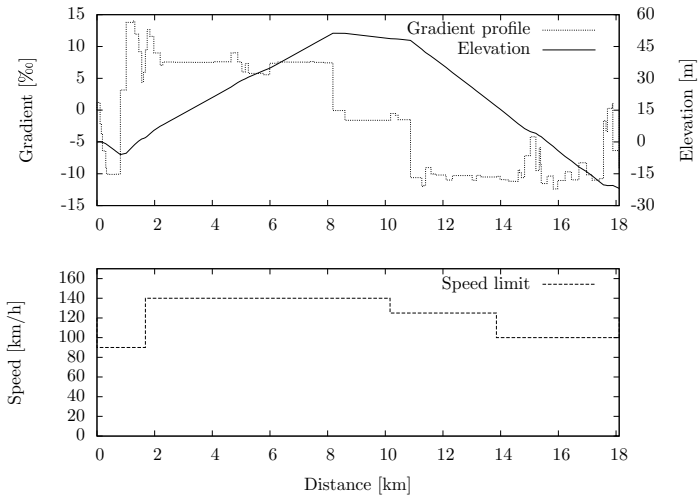


Energy efficient train trajectory (Trajectory II) assuming variable losses in the propulsion system (distance: 7.5 km, travel time: 400 s)

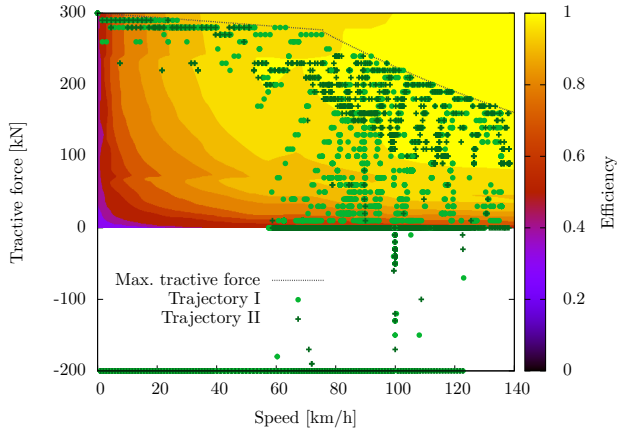


Comparison of Trajectory I (constant losses) and II (variable losses)
(distance: 7.5 km, travel time: 400 s)

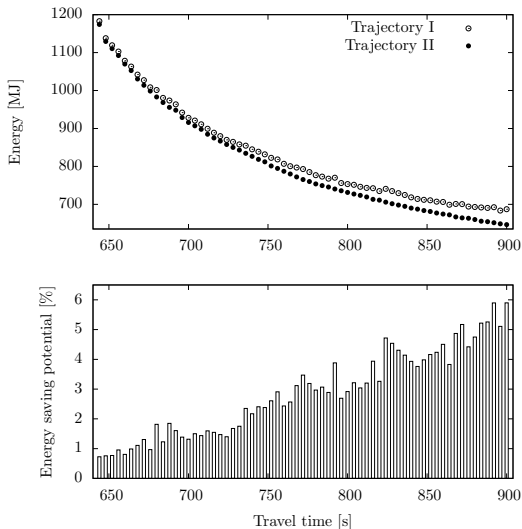
3 Comparison (mountainous scenario)



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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