TECHNISCHE UNIVERSITÄT DRESDEN

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

Evamarie Wießner
(German Aerospace Center (DLR), Institute of Transportation Systems)

Jürgen Krimmling, Birgit Jaekel, Martin Lehnert
(Dresden University of Technology)

Paris, 31.05.2017

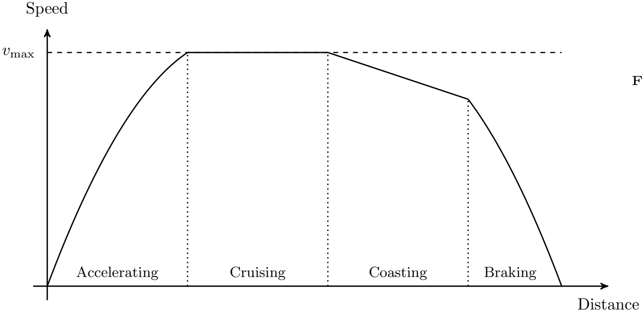
Optimizing train trajectories for energy consumption using a traction- and speed-dependent engine efficiency

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

1 Optimization problem

$$\dot{\mathrm{x}} = \begin{pmatrix} \mathrm{x}_2 \\ \frac{\mathrm{F}_{\mathrm{B,max}}}{\mathrm{m}} \mathrm{u}(\mathrm{t}, \mathrm{x}_2) - \frac{1}{\mathrm{m}} \mathrm{F}_{\mathrm{W}}(\mathrm{x}_2) - \mathrm{F}_{\mathrm{S}}(\mathrm{x}_1) \end{pmatrix} \tag{2a}$$

$$\mathrm{J} = \mathrm{E} = \mathrm{F}_{\mathrm{B,max}} \int_0^{\mathrm{t_F}} \frac{1}{2} \frac{1}{\eta} (\mathrm{u} + |\mathrm{u}|) \mathrm{x}_2 \, \mathrm{dt} \rightarrow \mathsf{min} \tag{2b}$$

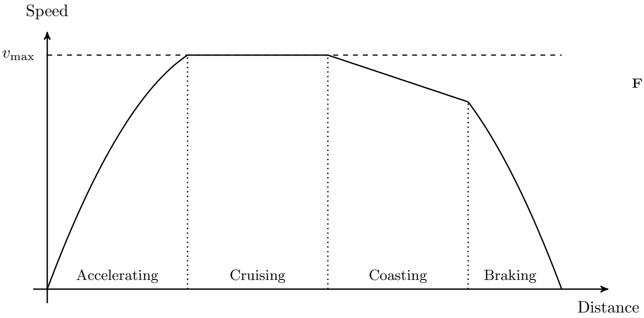


$\mathbf{E}$..energy
$\mathbf{F}_{\mathrm{B,max}}$..max. braking force
$\mathbf{F}_{\mathrm{S}}$..line resistance force
$\mathbf{F}_{\mathrm{W}}$..driving resistance force
$\mathbf{m}$..mass
$\mathbf{t}$..time
$\mathbf{t}_{\mathrm{F}}$..travel time
$\mathbf{u}$..control variable
$\mathbf{x}_1$..distance
$\mathbf{x}_2$..speed
η..efficiency

1 Optimization problem

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

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

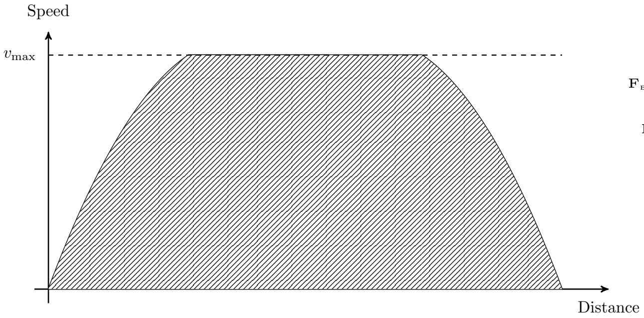


E..energy
$F_{B,max}$..max. braking force
F_S..line resistance force
F_W..driving resistance force
m..mass
t..time
t_F..travel time
u..control variable
x_1..distance
x_2..speed
η..efficiency

1 Optimization problem

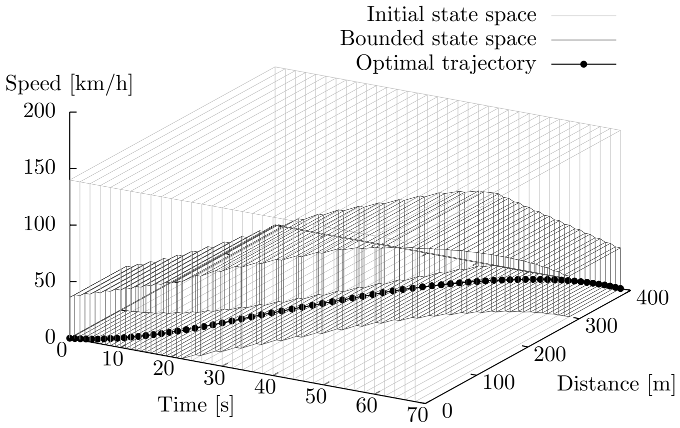
$$\dot{x} = \begin{pmatrix} x_2 \\ \frac{F_{B,max}}{m} u(t, x_2) - \frac{1}{m} F_W(x_2) - F_S(x_1) \end{pmatrix} \quad (2a)$$

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

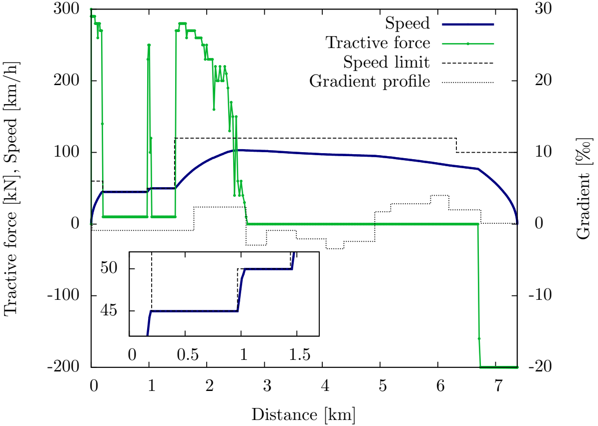


E..energy
$F_{B,max}$..max. braking force
F_S..line resistance force
F_W..driving resistance force
m..mass
t..time
t_F..travel time
u..control variable
x_1..distance
x_2..speed
η..efficiency

2 Dynamic programming

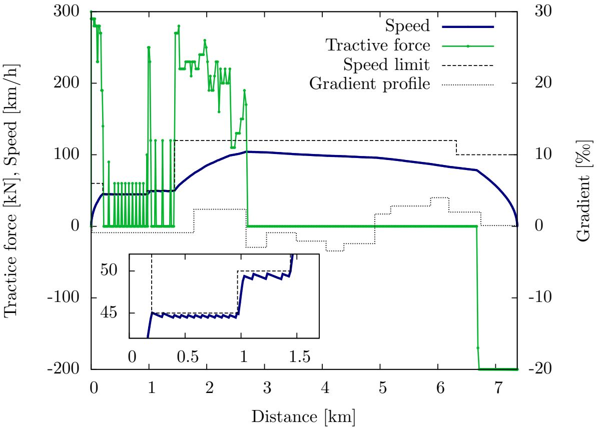


3 Comparison (flat scenario)

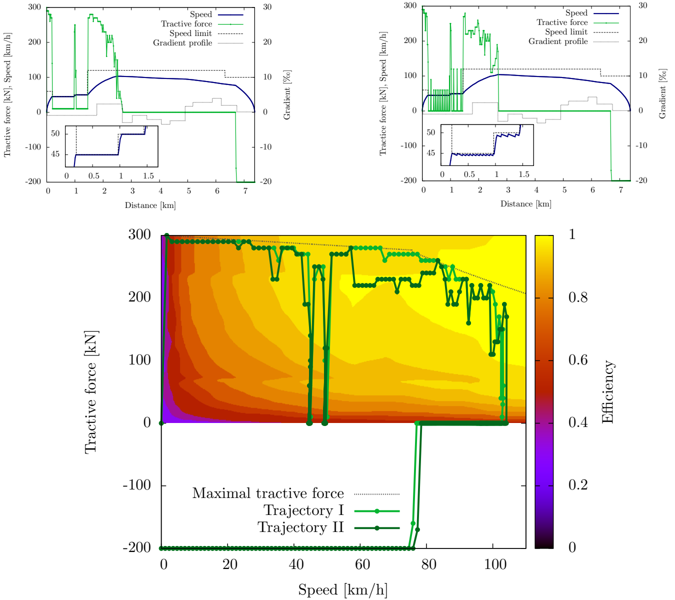


Energy efficient train trajectory (Trajectory I) assuming constant losses in the propulsion system (distance: 7.5 km, travel time: 400 s)

3 Comparison (flat scenario)

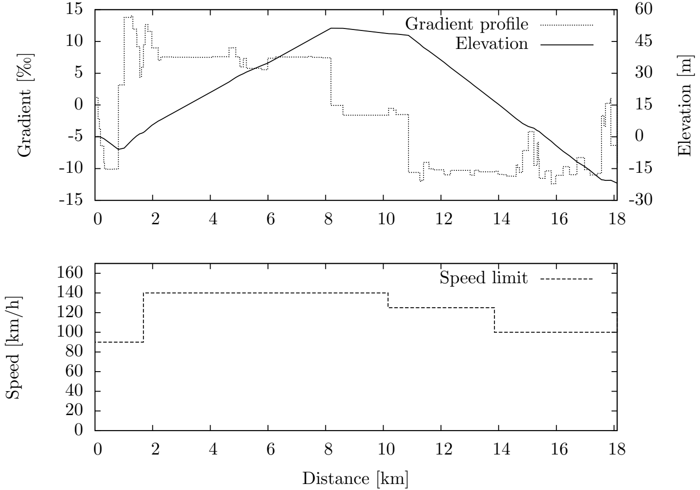


Energy efficient train trajectory (Trajectory II) assuming variable losses in the propulsion system (distance: 7.5 km, travel time: 400 s)

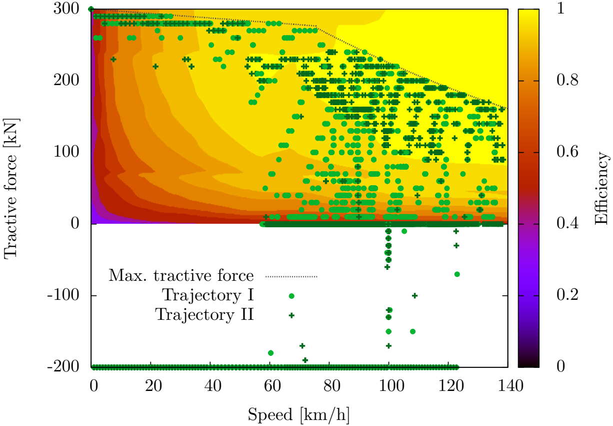


Comparison of Trajectory I (constant losses) and II (variable losses)
(distance: 7.5 km, travel time: 400 s)

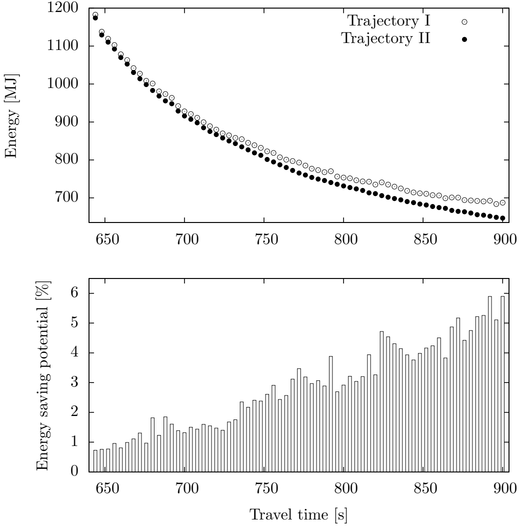
3 Comparison (mountainous scenario)



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