Benefits of Weight Reduction in High-Speed Train Operations

David Wennberg, Lic. Tech
Benefits of Weight Reduction in High-Speed Train Operations

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- Run cycle analysis
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  - Cycles
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- Weight Reduction
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Light Weighting

Why:
TSI regulations limits the weight of HS trains
• 17 ton / axel
• 1000 ton / 400 m train
  ➔ Limits the number of passengers

Environmental and economical driver:
• Reduced energy consumption
• Reduced wear
  - Reduced particle emissions

\[ x\% \text{ weight reduction} = y \text{ energy savings} = z \text{ reduced wear} = \delta \text{ SEK} \]
Run Cycle Analysis

- Represent **realistic** operating conditions
  - Standard in automotive industry
    - Drive cycles: City, highway, etc.
Run Cycle Analysis

- Simulated realistic run cycles
Run Cycle Analysis

- Simulated realistic run cycles
  - Track
Run Cycle Analysis

- Simulated realistic run cycles
  - Track
  - Cycle (traffic situation)

### Target speeds

#### 4 stops: Long distance traffic (**LD run**)
- 500,000 km/year

#### 14 stops: Regional traffic (**REG run**)
- 300,000 km/year
Reference Trains

5040

- Max power 5040 kW

7200

- Max power 7200 kW

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train type (-)</td>
<td>EMU</td>
</tr>
<tr>
<td>Number of cars (-)</td>
<td>6</td>
</tr>
<tr>
<td>Number of seats (-)</td>
<td>530</td>
</tr>
<tr>
<td>Mass (tons)</td>
<td>338</td>
</tr>
<tr>
<td>Adhevise weight (tons)</td>
<td>180</td>
</tr>
<tr>
<td>Max tractive force (kN)</td>
<td>228</td>
</tr>
<tr>
<td>Deceleration limit (m/s2)</td>
<td>0.6</td>
</tr>
<tr>
<td>Max Power (kW)</td>
<td>5040 / 7200</td>
</tr>
</tbody>
</table>

- Deceleration limit of 0.6 m/s2
- Blended braking style:
  Regenerative brakes as much as possible
Weight reduction

- Weight reductions
  - 97%
  - 93%
  - 90%
  - 86%
  - 80%

- Affects:
  - Adhesive weight
  - Use of mechanical / regenerative breaks
  - Acceleration characteristics
Scenarios

• How the weight reduction can be utilised

reference vehicle run time: $t_0$
reference vehicle total mass: $m_0$

1. Only mass reduction
- $m < m_0$
- $t < t_0$

2. Reduced top speed
- $m < m_0$
- $t = t_0$

3. Reduced motor power
- $m < m_0$
- $t = t_0$

4. Increased payload capacity
- $m = m_0$
- $t = t_0$
Simulations

- **Software STEC** (Simulation of Train Energy Consumption)
  - In-house KTH software programmed by Johan Öberg at MiW Konsult AB
  - Used in **TOSCA** (Technology Opportunities and Strategies toward Climate friendly trAnsport)
  - Simulated results have been verified by tests
    - Energy within 2%
    - Travel time within 1%

\[
D(v) = A + B \cdot v + C \cdot v^2
\]

\[
A \approx a_A \cdot \sum_{i=0}^{n} (30 + a_Q \cdot Q_i)
\]
Simulations - Output

• Output
  - Gross energy consumption
  - Regenerated energy from braking
    ➔ Net energy consumption
  - Reduced breaking energy
    ➔ Reduced brake wear
  - Run time

• Cost savings / extra income

\[ C_{year} = (0.594 \cdot dE_{tot} + 0.135 \cdot dE_M) \cdot S + K_i, \quad i = 1-3 \]

\[ K_1 = 3.51 \cdot 0.45 \cdot N \cdot S \cdot dT \]

\[ K_2 = 0 \]

\[ K_3 = 2200 \cdot dP \cdot \frac{r}{1 - (1 + r)^{-n}} \]
## Simulations - Simulated Trains

**Reference train: 7200**

### Scenario:
1. **Reduced run time**
   - LD: 12s, 26s, 37s, 52s, 73s
   - REG: 14s, 33s, 46s, 64s, 91s
2. **Reduced Top speed**
   - LD: 1%, 2%, 3%, 4%, 5.2%
   - REG: 3%, 5.5%, 7%, 8.6%, 10.5%
3. **Reduced motor power**
   - LD: 5.9%, 14.7%, 20.8%, 26.1%, 33.2%
   - REG: 10.3%, 18.2%, 24.4%, 31.4%, 39.3%
4. **Extra seats**
   - LD: 50, 118, 168, 236, 337
   - REG: 50, 118, 168, 236, 337

### Traffic:
- **LD**
  - 97%: 12s, 26s, 37s, 52s, 73s
  - 93%: 14s, 33s, 46s, 64s, 91s
  - 90%: 1% to 5.9%
  - 86%: 3% to 14.7%
  - 80%: 5.9% to 20.8%
- **REG**
  - 90%: 118, 168, 236, 337
  - 80%: 50, 118, 168, 236

*Simulations - Simulated Trains*

**Reference train:** 7200
Simulations - Simulated Trains

Reference train: 5040

Scenario:
1: Reduced run time
2: Reduced Top speed
3: Reduced motor power
4: Extra seats

Traffic: LD REG LD REG LD REG LD REG

97%
93%
90%
86%
80%

weight

Scenario 1: Reduced run time
Scenario 2: Reduced Top speed
Scenario 3: Reduced motor power
Scenario 4: Extra seats

Traffic: LD REG LD REG LD REG LD REG
Simulations - Simulated Trains

Summary:
- 40 virtual trains for each reference train
- Scenario 1, 2 and 3: Values derived by simulations
  - 2 and 3 < 2sec diff. compared to ref. vehicles
Results (scenario 1-3)

- Reduced net energy consumption
Results (scenario 1-3)

- Reduced mechanical breaking energy
Results (scenario 4)

\[ I_i = 1 - \frac{n_0}{n_{4,i}} \]

Number of seats
Results – cost savings / extra income

Considers only energy and brake wear
# Results – summary values

\[
\text{\% reduced energy consumption} \quad \text{\% weight reduction}
\]

<table>
<thead>
<tr>
<th></th>
<th>LD 5040</th>
<th>LD 7200</th>
<th>REG 5040</th>
<th>REG 7200</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario 1</strong></td>
<td>0.37</td>
<td>0.37</td>
<td>0.49</td>
<td>0.47</td>
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<tr>
<td><strong>Scenario 2</strong></td>
<td>0.54</td>
<td>0.49</td>
<td>0.83</td>
<td>0.76</td>
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<tr>
<td><strong>Scenario 3</strong></td>
<td>0.32</td>
<td>0.23</td>
<td>0.42</td>
<td>0.28</td>
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<tr>
<td><strong>Scenario 4</strong></td>
<td>1.93</td>
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Results – summary values

% reduced energy consumption

% weight reduction

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Results – summary values

% reduced energy consumption
% weight reduction

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<th></th>
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<th>Aviation</th>
<th>Maritime</th>
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<tbody>
<tr>
<td></td>
<td>0.3 - 0.8</td>
<td>0.25 - 0.75</td>
<td>&gt;1</td>
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Thank you for your attention!

Questions?

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