Lightweight Design in Railway Vehicles – Energy and Cost Potential Assessment

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Outline

- Influence Factors on Energy Consumption of Trains
- Energy savings potential through lightweight design
- Lifetime profit by reducing vehicle mass
- Conclusion
Influence Factors on Energy Consumption of Trains

- Propulsion Concept & Efficiency
- Onboard Energy
- Driving Style
- Parked Train Management
- Aerodynamics
- Vehicle Mass
- Operational Aspects
- Timetable
Energy Savings by Lightweight Design

Literature survey

- Energy savings increase with decreasing station distances
- Variations in savings potential

Weaknesses:
- Percentage-based and mass-based data incomparable
- Lack of information about general conditions and service profiles
- Energy savings only for electric propulsion
- Brake energy recuperation?

⇒ Standardized method for savings calculation required
Service Profiles for Passenger Transport
UIC/UNIFE Technical Recommendation 100-001

Definition of service profiles for Highspeed, Intercity, Regional and Suburban passenger transport

<table>
<thead>
<tr>
<th></th>
<th>Suburban</th>
<th>Regional</th>
<th>Intercity</th>
<th>High-Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum speed km/h</td>
<td>120</td>
<td>140</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Total distance km</td>
<td>40</td>
<td>70</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Number of stations</td>
<td>12</td>
<td>15</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Min. station distance km</td>
<td>2</td>
<td>2</td>
<td>15</td>
<td>90</td>
</tr>
<tr>
<td>Max. station distance km</td>
<td>7</td>
<td>10</td>
<td>60</td>
<td>210</td>
</tr>
<tr>
<td>Mileage km/year</td>
<td>100000</td>
<td>130000</td>
<td>275000</td>
<td>550000</td>
</tr>
</tbody>
</table>
Service Profiles for Passenger Transport
UIC/UNIFE Technical Recommendation 100-001

- Definition of service profiles for Highspeed, Intercity, Regional and Suburban passenger transport

- Travel times and dwell times in stations defined in a timetable
- Free choice of velocity profile as long as timetable is kept
Driving Strategies
Comparison of wheel energy consumption

Predefined v(t)-Profile:

- linear relationship between mass reduction and wheel energy

Variable v(t)-Profile:

- nonlinear relationship of mass reduction and wheel energy
Driving Strategies
Comparison of wheel energy consumption

Predefined $v(t)$-Profile:
- Linear relationship between mass reduction and wheel energy

Variable $v(t)$-Profile:
- Nonlinear relationship of mass reduction and wheel energy
- Variable $v(t)$ reflects real world driving style
Energy Savings by Lightweight Design
Simulation Model

Wheel Forces

Davis-Resistance:
\[ F_{\text{Res}} = A \cdot m_{\text{static}} + B \cdot v + C \cdot v^2 \]

Control Unit incl. Velocity Profile, Force & Power Limits

Drive Train Efficiencies

Vehicle Mass

Track Description here: Flat Track
## Energy Savings by Lightweight Design
Train data used in simulations

<table>
<thead>
<tr>
<th></th>
<th>DMU BR611</th>
<th>EMU BR423</th>
<th>HST BR403</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum speed</strong></td>
<td>km/h</td>
<td>160</td>
<td>140</td>
</tr>
<tr>
<td><strong>Occupied mass</strong></td>
<td>tons</td>
<td>115.7</td>
<td>119.4</td>
</tr>
<tr>
<td><strong>UIC service profiles</strong></td>
<td>Suburban, Regio, IC</td>
<td>Suburban, Regio, IC</td>
<td>IC, High speed</td>
</tr>
<tr>
<td>Max. tractive effort</td>
<td>kN</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Max. drive power at wheel</td>
<td>kW</td>
<td>900</td>
<td>2350</td>
</tr>
<tr>
<td>Recovery power at wheel</td>
<td>kW</td>
<td>0</td>
<td>2350</td>
</tr>
<tr>
<td>Efficiency of drive/recoveries</td>
<td>%</td>
<td>30 / 0</td>
<td>80 / 75</td>
</tr>
<tr>
<td>Resistance Force: Davis A</td>
<td>N/t</td>
<td>17</td>
<td>23</td>
</tr>
<tr>
<td>Resistance Force: Davis B</td>
<td>Ns/m</td>
<td>37.1</td>
<td>48.2</td>
</tr>
<tr>
<td>Resistance Force: Davis C</td>
<td>Ns²/m²</td>
<td>3.758</td>
<td>6.480</td>
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</tbody>
</table>
Simulation Results
Electric and fuel energy savings per ton

<table>
<thead>
<tr>
<th>Train Type</th>
<th>Suburban kWh/100km</th>
<th>Regional kWh/100km</th>
<th>Intercity kWh/100km</th>
<th>High-Speed kWh/100km</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMU BR611</td>
<td>22.0</td>
<td>20.6</td>
<td>5.2</td>
<td>0.7</td>
</tr>
<tr>
<td>EMU BR423</td>
<td>4.0</td>
<td>3.8</td>
<td>1.3</td>
<td>0.7</td>
</tr>
<tr>
<td>HST BR403</td>
<td>1.2</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Suburban, Regional, Intercity, High-Speed
Simulation Results
DLR results compared to literature values

→ Similar results for electric propulsion in regional and intercity profile
→ Savings potential in diesel propulsion significantly higher
Energy Savings by Lightweight Design
Energy costs at 15 and 30 years lifetime

Assumptions for NPV lifetime saving potential:
- Lifetime 15 and 30 years
- Annual mileage acc. to UIC service profiles
- Costs for energy taken from wire: 14.12 €-Ct/kWh (2013)
- Compensation for energy fed back to grid: 10.6 €-Ct/kWh (2013)
- Diesel: 1.20 €/l (2013)

Scenario:
- Energy cost increase / a: 2%
- Discount rate: 6 %
  - Real interest rate: ca. 4 %
Energy Savings by Lightweight Design
Effects of discounting and energy cost inflation

Lifetime Energy Cost Reduction at 10 % Mass Reduction
BR611 Suburban
- variation of interest rate and energy price inflation
  30 years

annual energy price inflation
discount rate
Energy Savings by Lightweight Design
Effects of discounting and energy cost inflation

Long lifetimes lead to tremendous impacts of discount rate and annual energy cost inflation on resulting total saving potential.

→ major source of uncertainty
Energy Savings by Lightweight Design
Lifetime energy cost benefit per kg mass reduction

Conclusions:

- Lifetime saving potential by lightweight design in EMUs 3 – 5 times bigger than in DMUs (per kg)
- Lightweight Design more worthwhile in Diesel-driven vehicles (as no energy can be recuperated)

Important factors to consider:
- Amortisation time
- Discount rate
- Energy inflation
Summary

- Simulations show significant energy savings potential through lightweight design
- Energy savings potential in DMUs up to four times higher than in electric propulsion
- Lifetime profit through lightweight design between 6 – 18 Euro/kg in electric propulsion and 21 - 66 Euro/kg in DMUs