# Benefits of Weight Reduction in High-Speed Train Operations

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... research where ECOlogy & ECOnomy meet

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# Benefits of Weight Reduction in High-Speed Train Operations

Content:

- Light weighting
  - Why?
- Run cycle analysis
  - Track
  - Cycles
- Reference Trains
- Weight Reduction
- Scenarios
- Simulations
- Results

# 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 emmisons

$$x\% \text{ weight reduction} = y \text{ energy savings}$$

$$= z \text{ reduced wear}$$

$$= \delta \text{ SEK}$$

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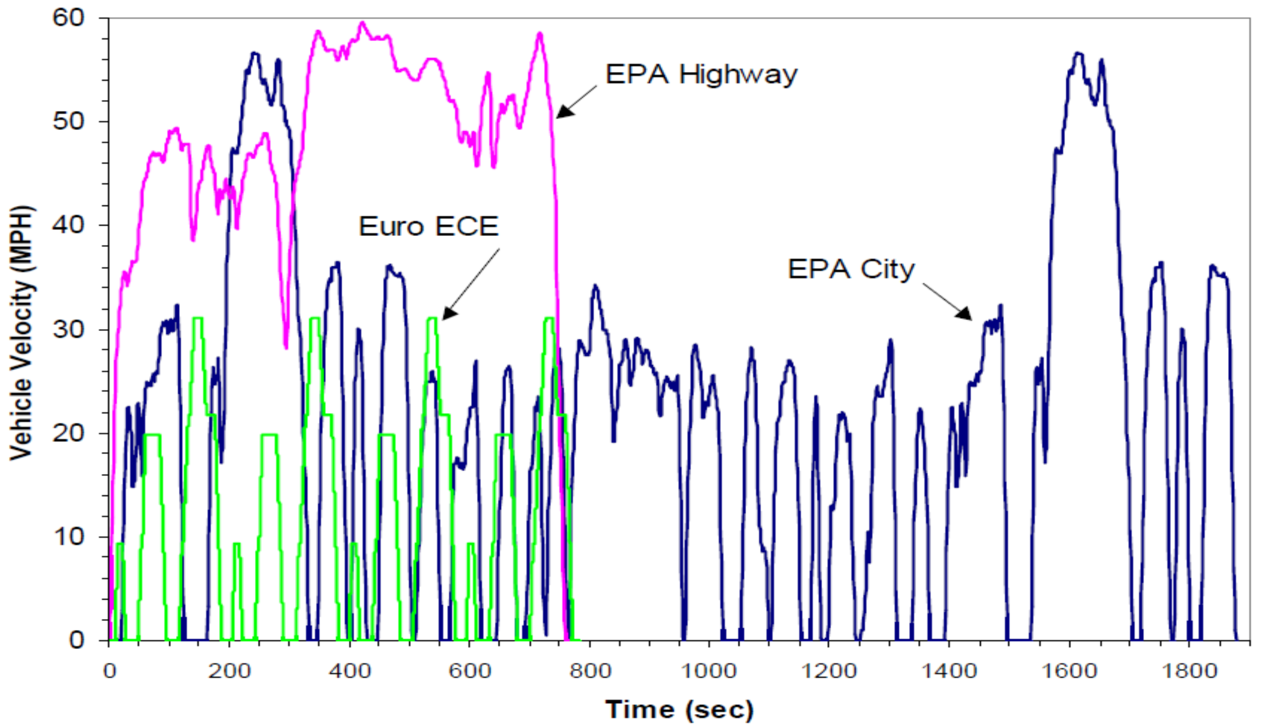
# Run Cycle Analysis

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



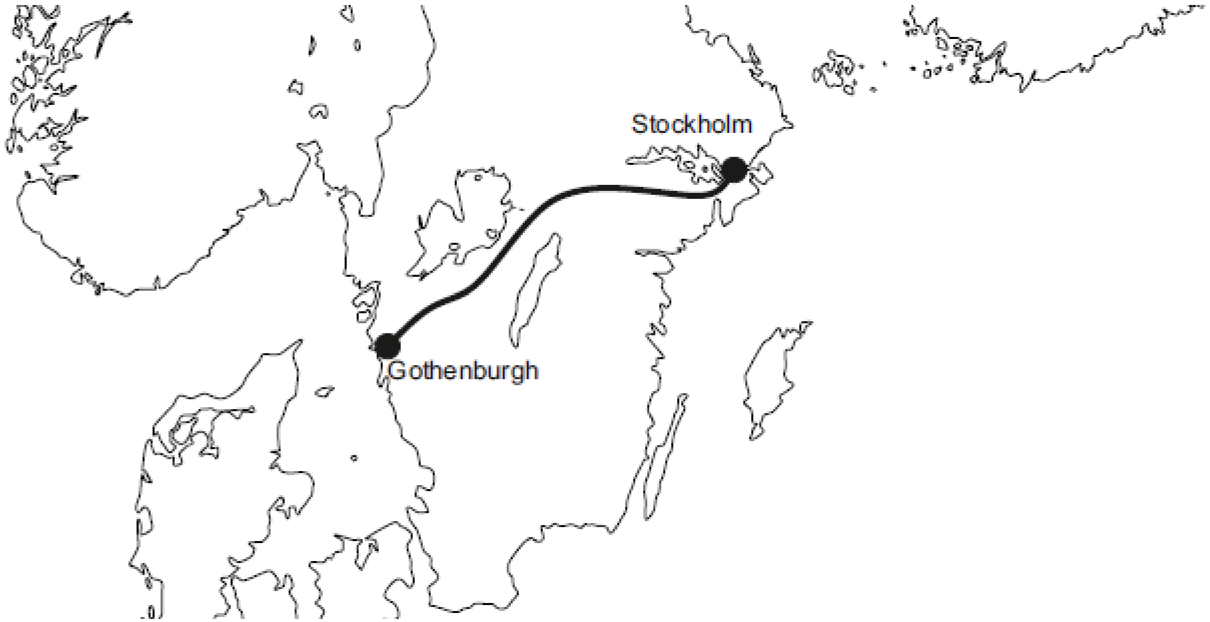

*A rapport by RICARDO Inc.*

# Run Cycle Analysis

- Simulated realistic run cycles

# Run Cycle Analysis

- Simulated realistic run cycles
  - Track



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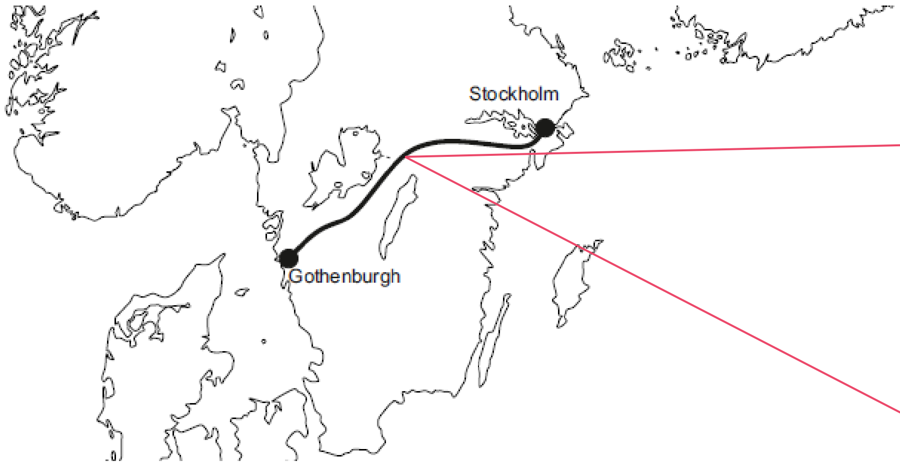
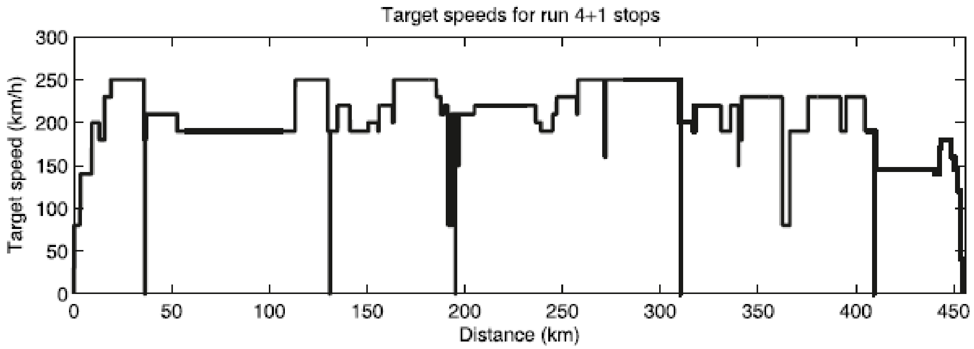
# Run Cycle Analysis

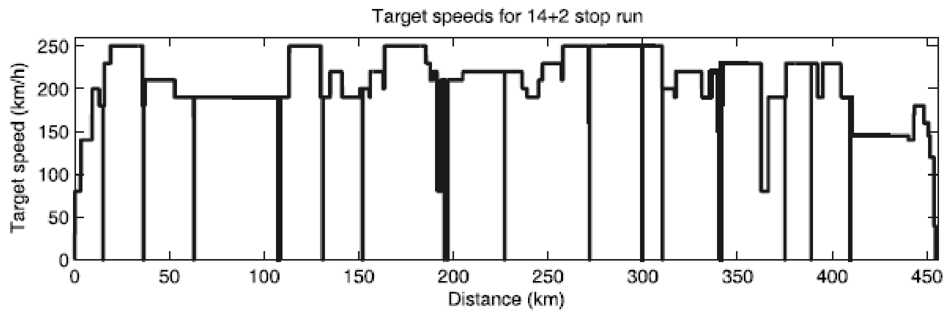
- Simulated realistic run cycles
  - Track
  - Cycle (traffic situation)




## Target speeds

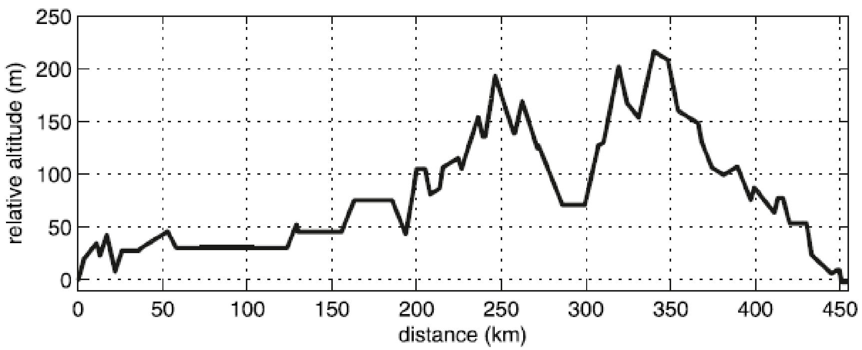



4 stops: Long distance traffic (***LD run***)
*500,000 km/year*




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

## Altitude



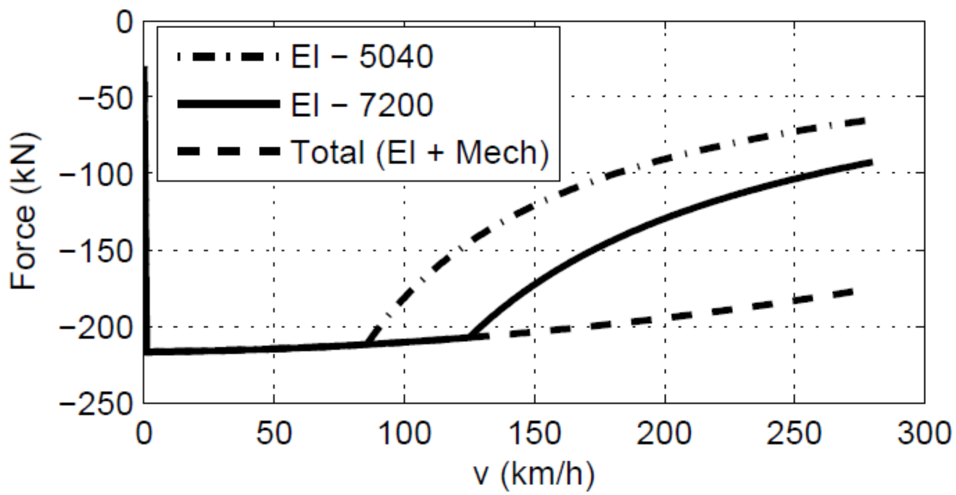
# Reference Trains

| **5040** | **7200** |
| --- | --- |
| • Max power 5040 kW | • Max power 7200 kW |

| **Property** | **Value** |
| --- | --- |
| Train type (-) | EMU |
| Number of cars (-) | 6 |
| Number of seats (-) | 530 |
| Mass (tons) | 338 |
| Adhevise weight (tons) | 180 |
| Max tractive force (kN) | 228 |
| Deceleration limit (m/s2) | 0.6 |
| Max Power (kW) | 5040 / 7200 |

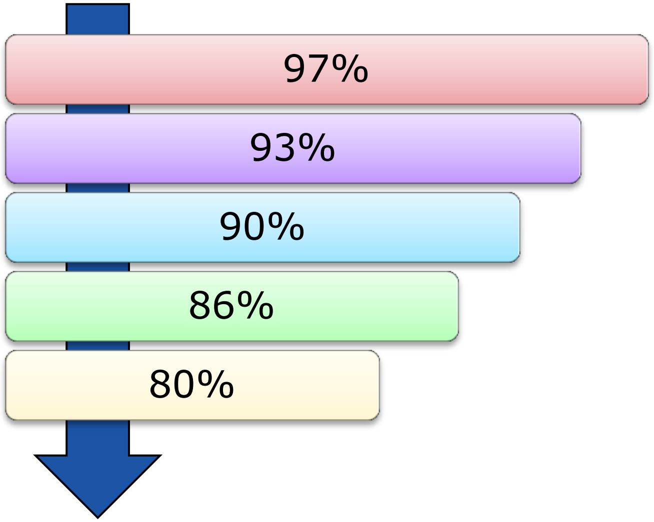
- Deceleration limit of 0.6 m/s2
- Blended braking style:

  Regenerative brakes as much as possible



# Weight reduction

- Weight reductions




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

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# Scenarios

- How the weight reduction can be utilised

reference vehicle run time: $t_0$

reference vehicle total mass: $m_0$

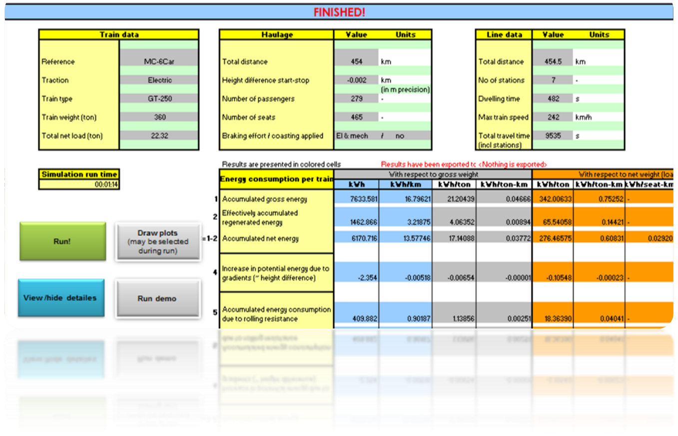
**1. Only mass reduction**
- $m < m_0$
- $t < t_0$

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

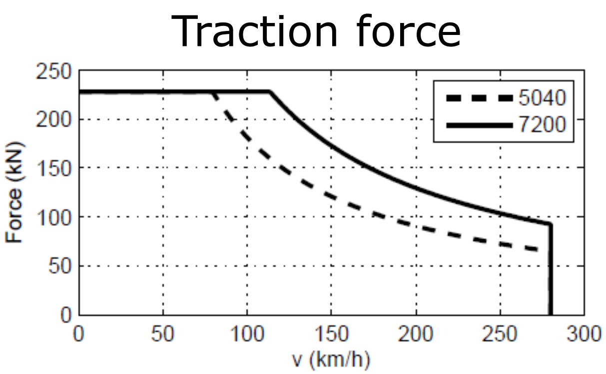
**3. Reduced motor power**
- $m < m_0$
- $t = t_0$

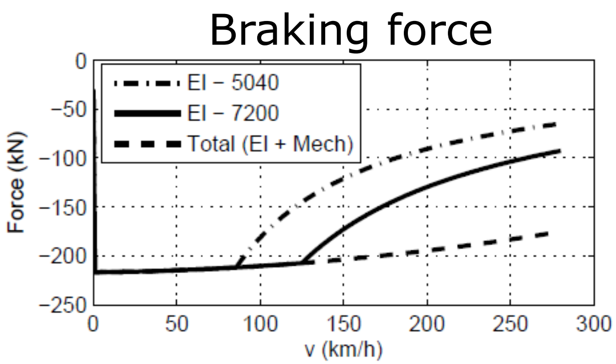
**4. Increased payload capacity**
- $m = m_0$
- $t = t_0$

# 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%**




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

$$A \approx a_A \cdot \sum_{i=0}^{n} (30 + a_Q \cdot Q_i)$$

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# 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

$$C_{year} = (0.594 \cdot dE_{tot} + 0.135 \cdot dE_M) \cdot S + K_i, \quad i = 1\text{–}3$$

$$K_1 = 3.51 \cdot 0.45 \cdot N \cdot S \cdot dT$$

$$K_2 = 0$$

$$K_3 = 2200 \cdot dP \cdot \frac{r}{1 - (1 + r)^{-n}}$$

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# Simulations - Simulated Trains

Reference train: **7200**

| 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% | 12s | 14s | 1% | 3% | 5.9% | 10.3% | 50 | 50 |
| 93% | 26s | 33s | 2% | 5.5% | 14.7% | 18.2% | 118 | 118 |
| 90% | 37s | 46s | 3% | 7% | 20.8% | 24.4% | 168 | 168 |
| 86% | 52s | 64s | 4% | 8.6% | 26.1% | 31.4% | 236 | 236 |
| 80% | 73s | 91s | 5.2% | 10.5% | 33.2% | 39.3% | 337 | 337 |

weight

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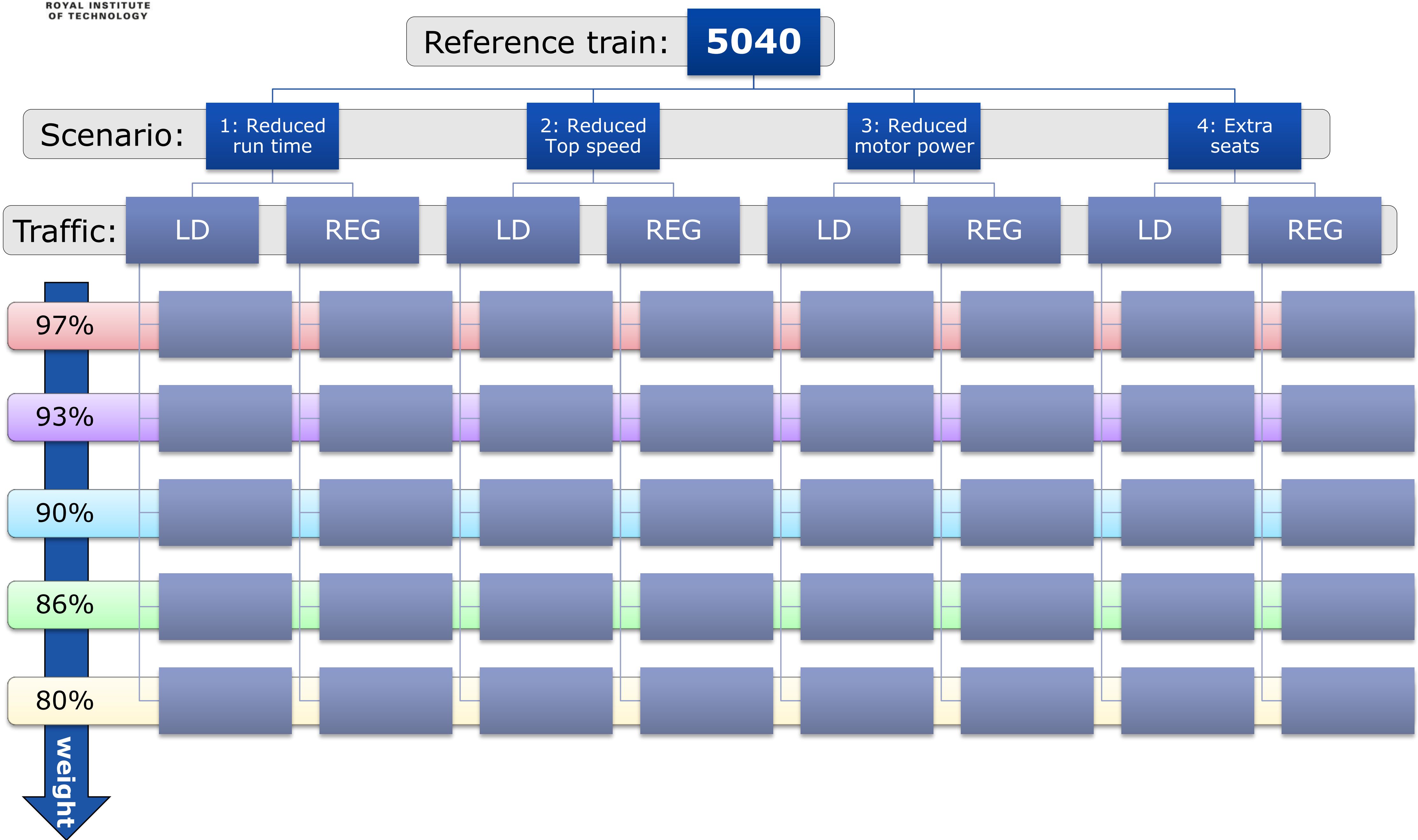
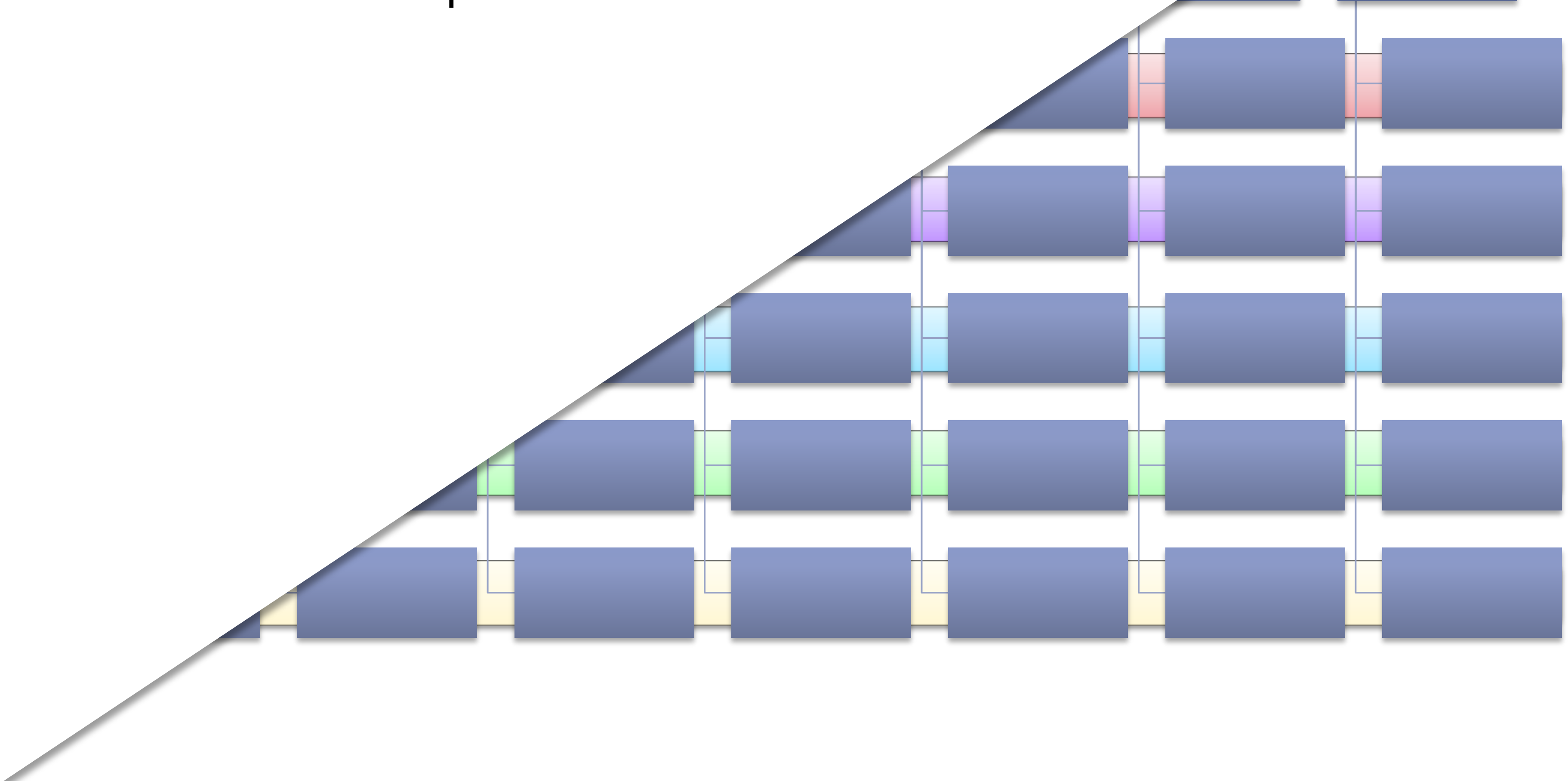
# Simulations - Simulated Trains



# Simulations - Simulated Trains

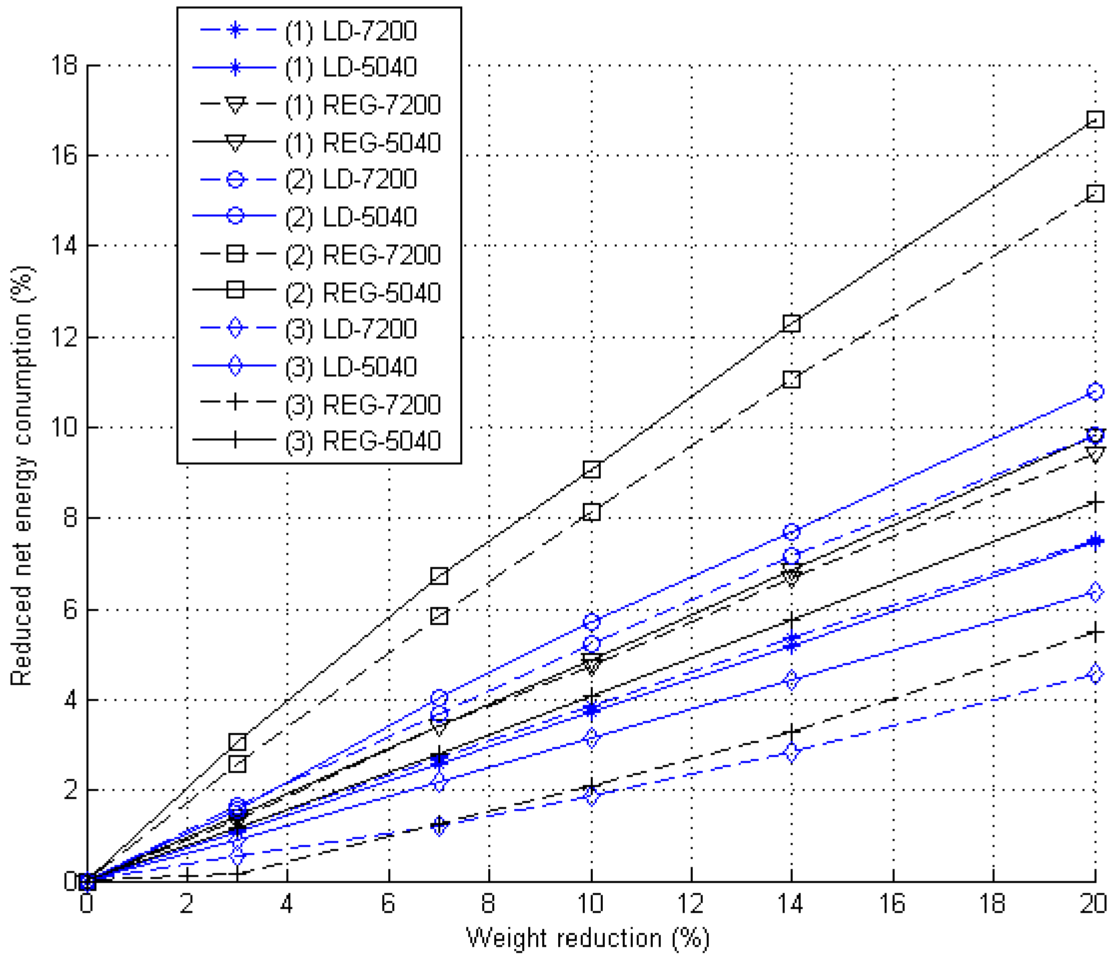
Summary:

- 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



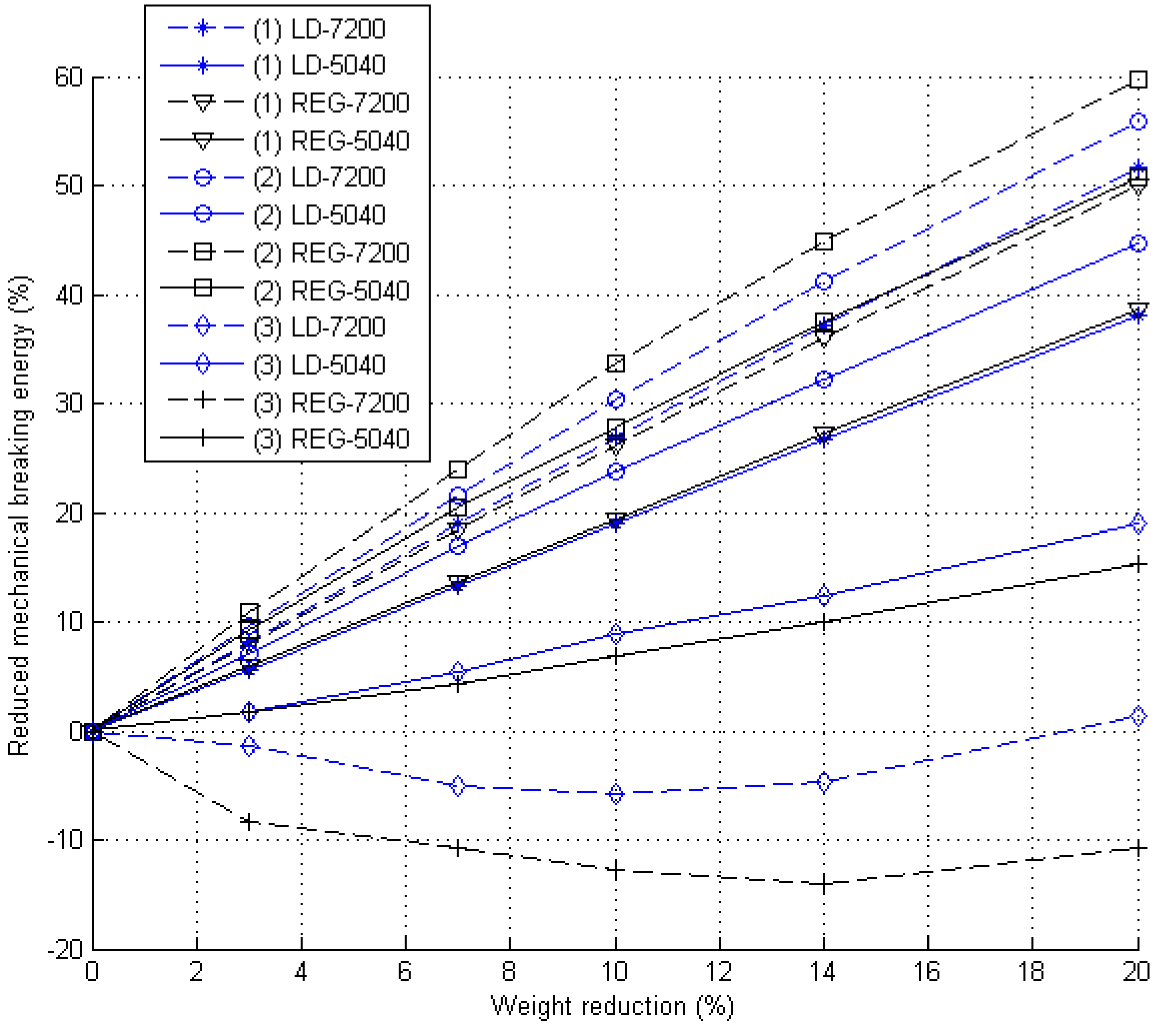
# Results (scenario 1-3)

- Reduced net energy consumption

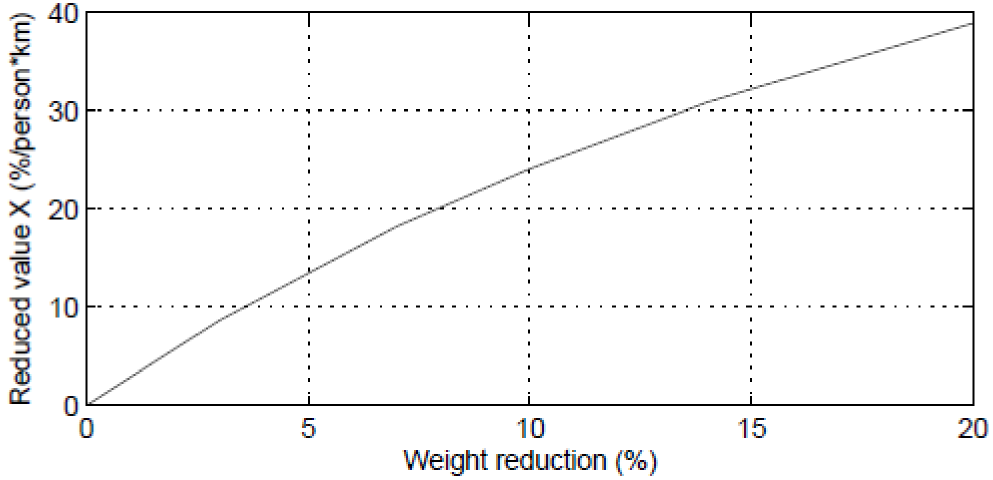


# Results (scenario 1-3)

- Reduced mechanical breaking energy



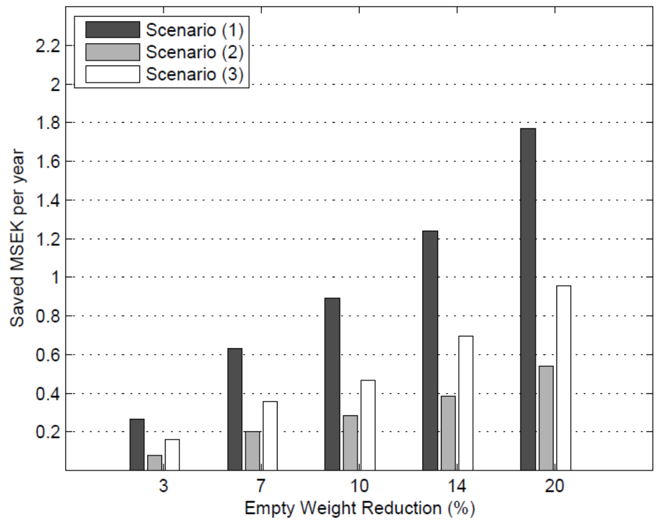
# Results (scenario 4)



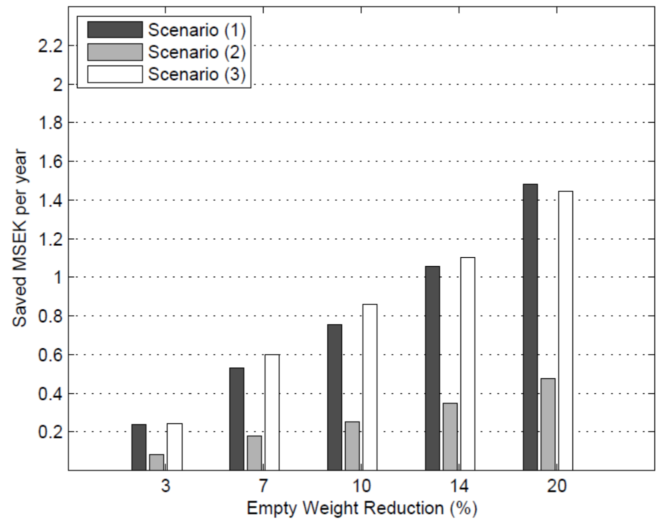

$$I_i = 1 - \frac{n_0}{n_{4,i}}$$

Number of seats

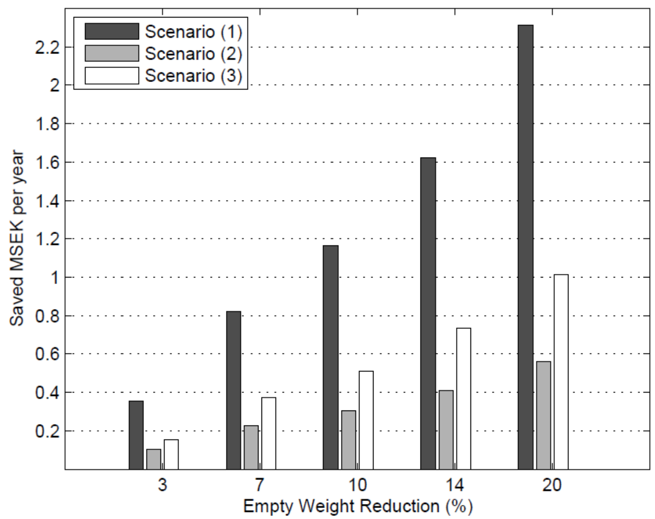
# Results – cost savings / extra income



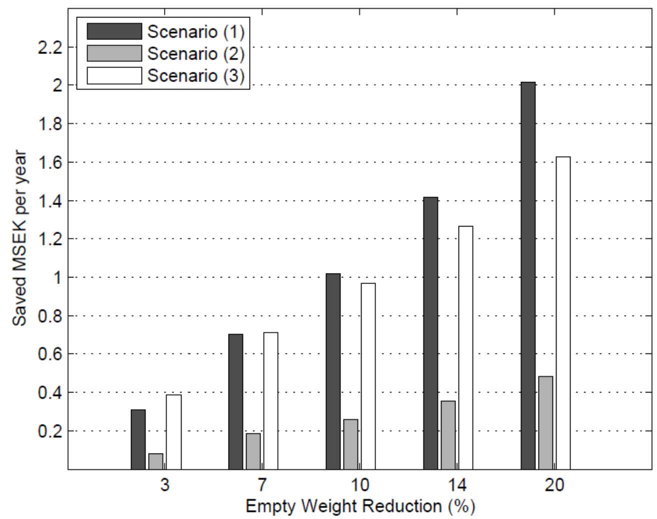

(a) LD 5040




(b) LD 7200




(c) REG 5040




(d) REG 7200

Considers *only* energy and brake wear

# Results – summary values

$$\frac{\%\ \text{reduced energy consumption}}{\%\ \text{weight reduction}}$$

| | LD 5040 | LD 7200 | REG 5040 | REG 7200 |
|---|---|---|---|---|
| **Scenario 1** | 0.37 | 0.37 | 0.49 | 0.47 |
| **Scenario 2** | 0.54 | 0.49 | 0.83 | 0.76 |
| **Scenario 3** | 0.32 | 0.23 | 0.42 | 0.28 |
| **Scenario 4** | 1.93 | 1.93 | 1.93 | 1.93 |

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| Automotive | Aviation | Maritime |
|---|---|---|
| 0.3 - 0.8 | 0.25 - 0.75 | >1 |

# Thank you for your attention!

Questions?

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