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Benefits of Weight Reduction in High-Speed Train Operations

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... research where ECOlogy & ECONomy meet

VINNOVA

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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

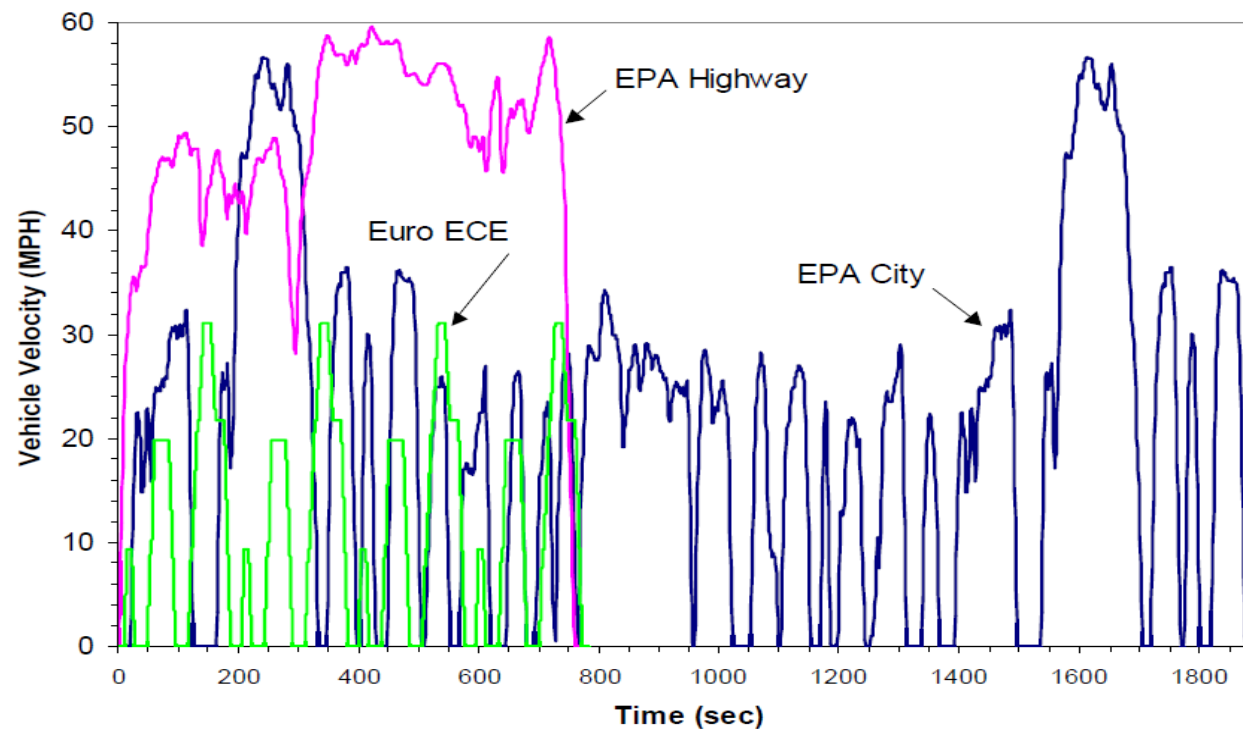
Environmental and economical driver:

- Reduced energy consumption
- Reduced wear
 - Reduced particle emissions

$$\begin{aligned}x\% \text{ weight reduction} &= y \text{ energy savings} \\ &= z \text{ reduced wear} \\ &= \delta \text{ SEK}\end{aligned}$$

Run Cycle Analysis

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





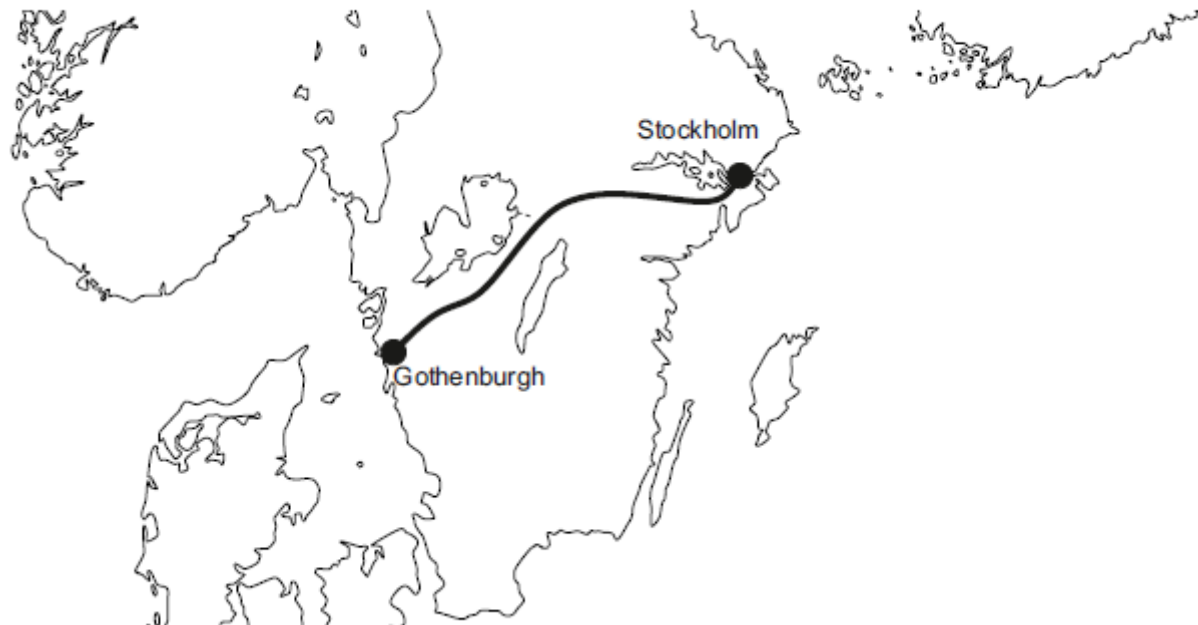
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Run Cycle Analysis

- **Simulated realistic** run cycles

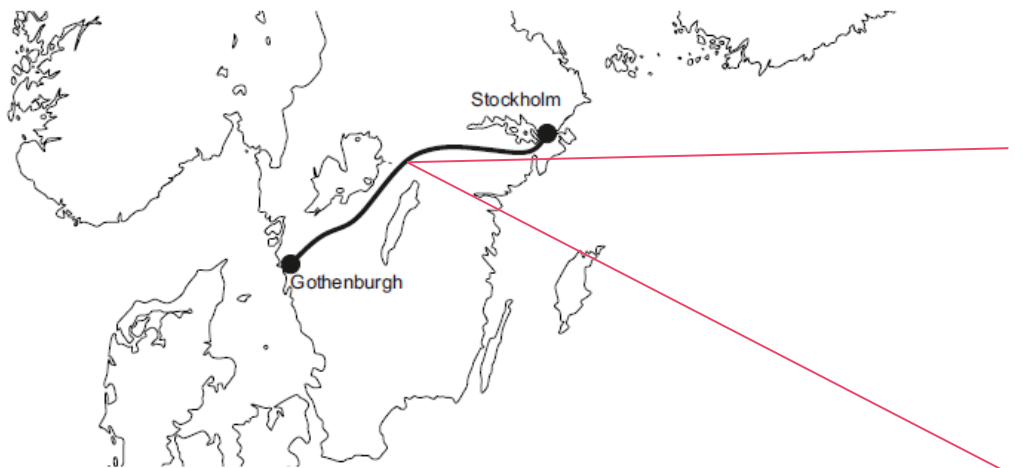
Run Cycle Analysis

- Simulated realistic run cycles
 - Track

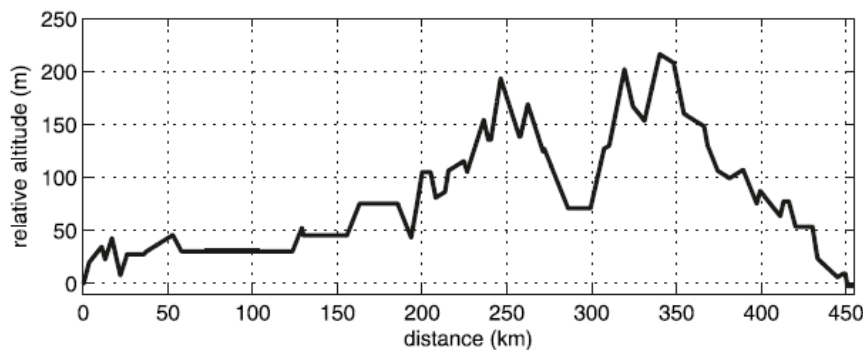


Run Cycle Analysis

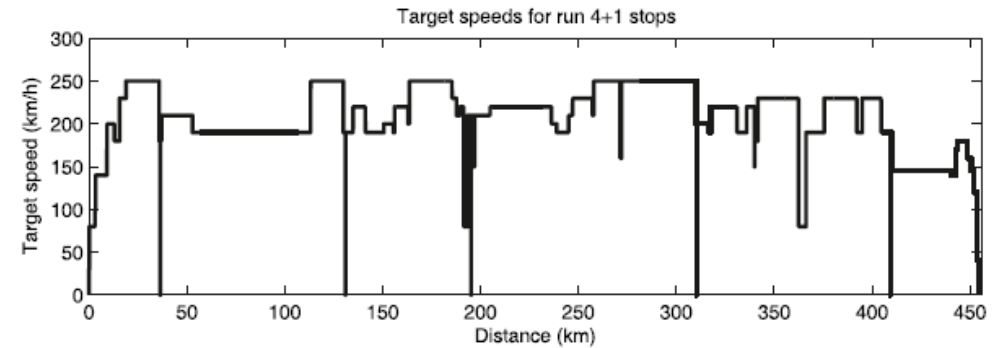
- Simulated realistic run cycles
 - Track
 - Cycle (traffic situation)



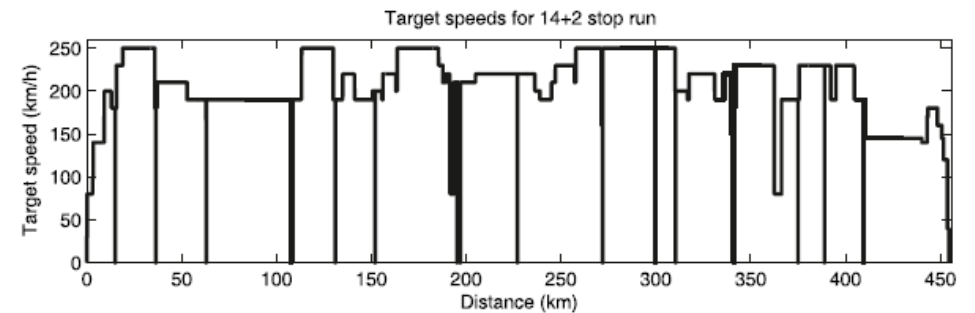
Altitude



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

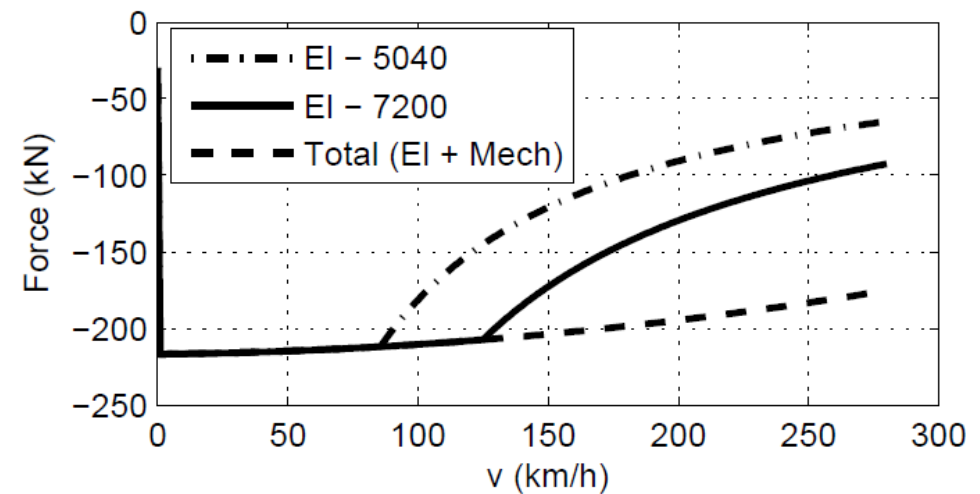
- Max power 7200 kW

Property	Value
Train type (-)	EMU
Number of cars (-)	6
Number of seats (-)	530
Mass (tons)	338
Adhevisse weight (tons)	180
Max tractive force (kN)	228
Deceleration limit (m/s ²)	0.6
Max Power (kW)	5040 / 7200



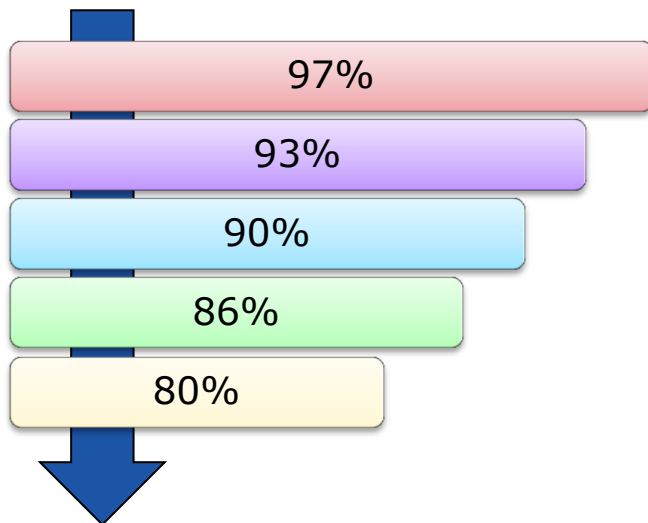
- Deceleration limit of 0.6 m/s²
- **Blended braking style:**

Regenerative brakes as much as possible



Weight reduction

- Weight reductions



- Affects:

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

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

- $m = m_0$
- $t = t_0$



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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**

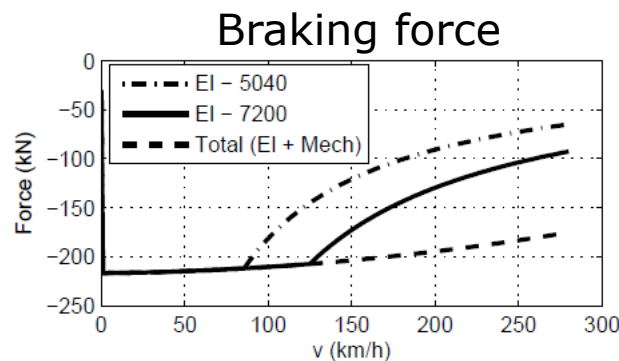
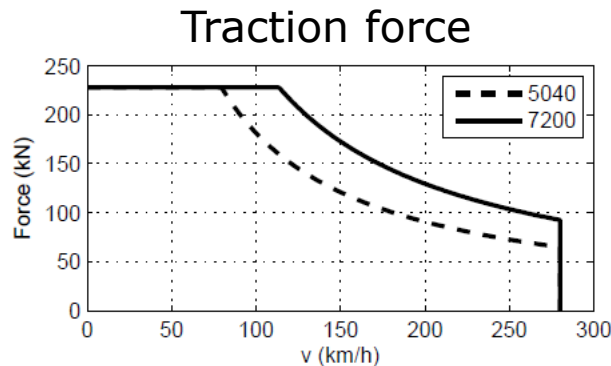
- **Energy within 2%**

- **Travel time within 1%**

FINISHED!

Train data		Hausage		Line data			
Reference	Value	Value	Units	Value	Units		
MC-Car	454	Total distance	454	km	Total distance	454.5	km
Traction	Electric	Height difference start-stop	-0.002	km	No of stations	7	-
Train type	GT-250	Number of passengers	279	(in precision)	Dwelling time	492	s
Train weight (ton)	380	Number of seats	465	-	Max train speed	242	km/h
Total net load (ton)	22.32	Braking effort / coasting applied	EI & mech	/ no.	Total travel time (incl stations)	9535	s

Simulation run time		Results are presented in colored cells				
Value	Units	With respect to gross weight		With respect to gross weight		
Value	Units	LVh	LVh/ton	LVh/ton-km	LVh/ton-km	
Accumulated gross energy	7633.501	9.79625	21.04439	0.04664	342.06033	0.75252
Effectively accumulated regenerated energy	162.888	3.28875	4.06352	0.00954	62.54059	0.14421
Accumulated net energy	870.778	13.07746	17.94089	0.03772	276.40575	0.60831
Increase in potential energy due to gradients (↑ height difference)	-2.354	-0.00518	-0.00654	-0.00001	-0.19544	-0.00023
Accumulated energy consumption due to rolling resistance	469.882	0.90887	11.01856	0.02225	91.26280	0.20441



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

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

Simulations - Output

- Output

- Gross energy consumption
- Regenerated energy from braking

→ **Net energy consumption**

- Reduced braking 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

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 ↓

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%

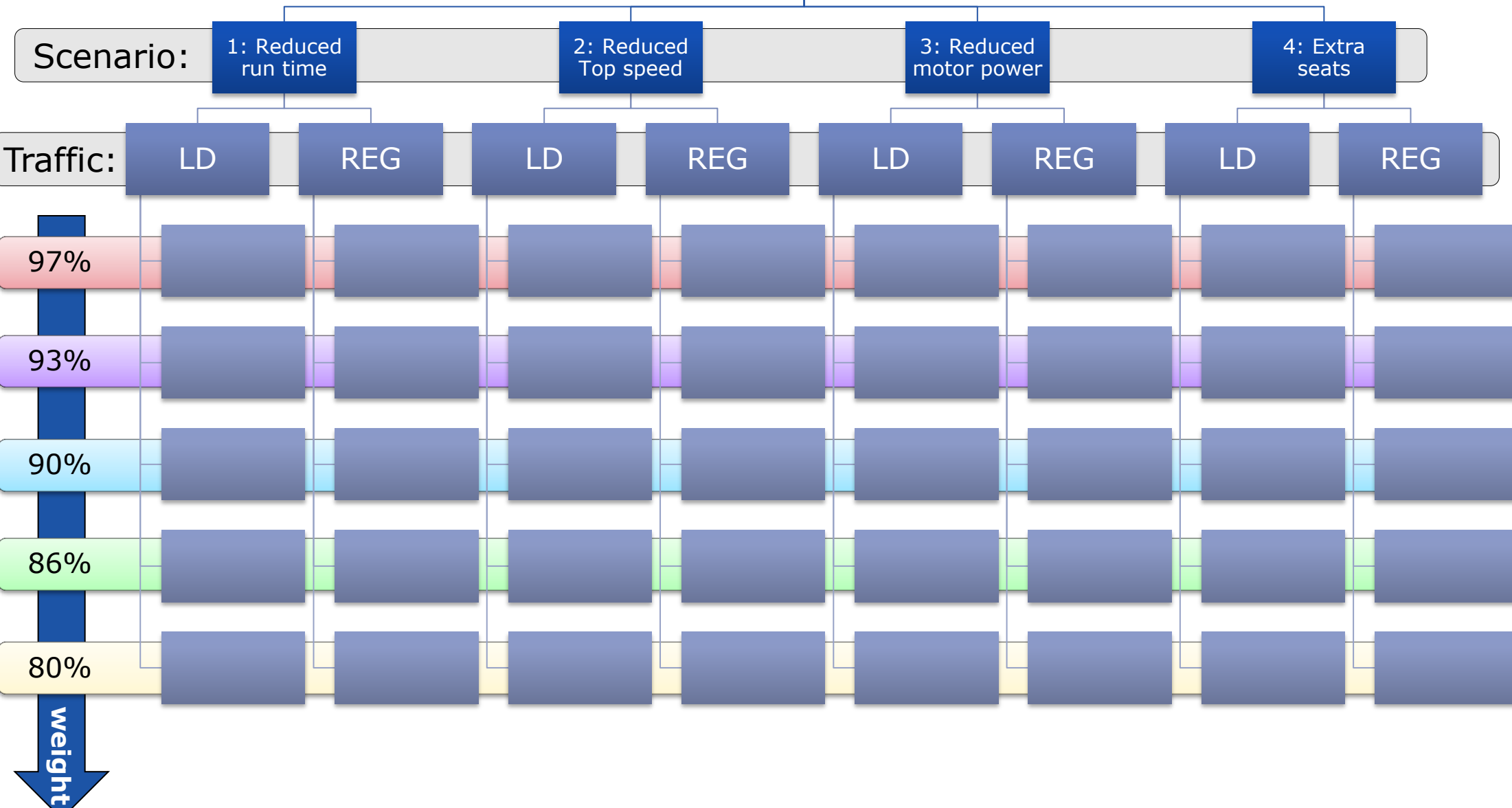
93%

90%

86%

80%

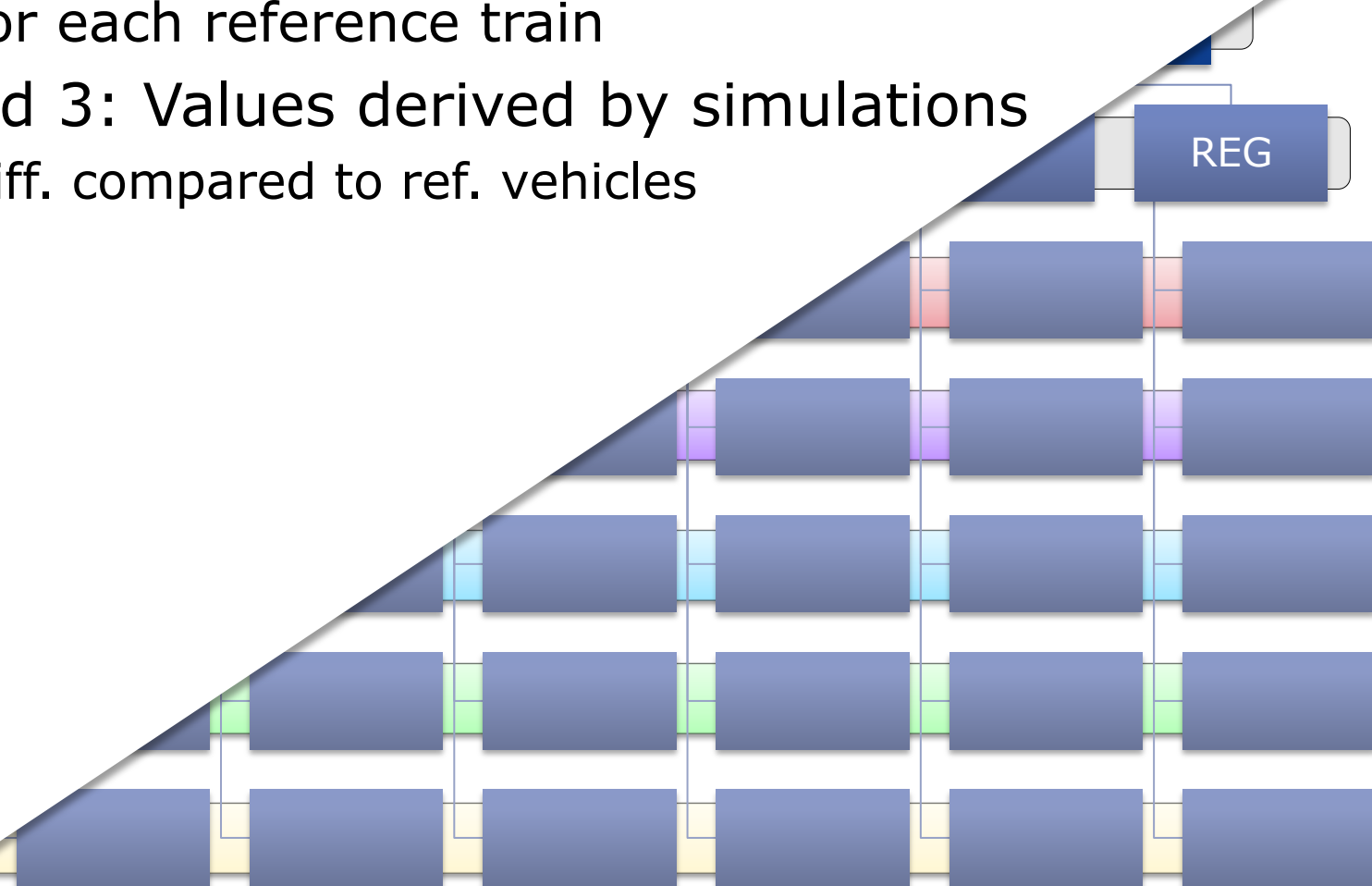
weight ↓



Simulations - Simulated Trains

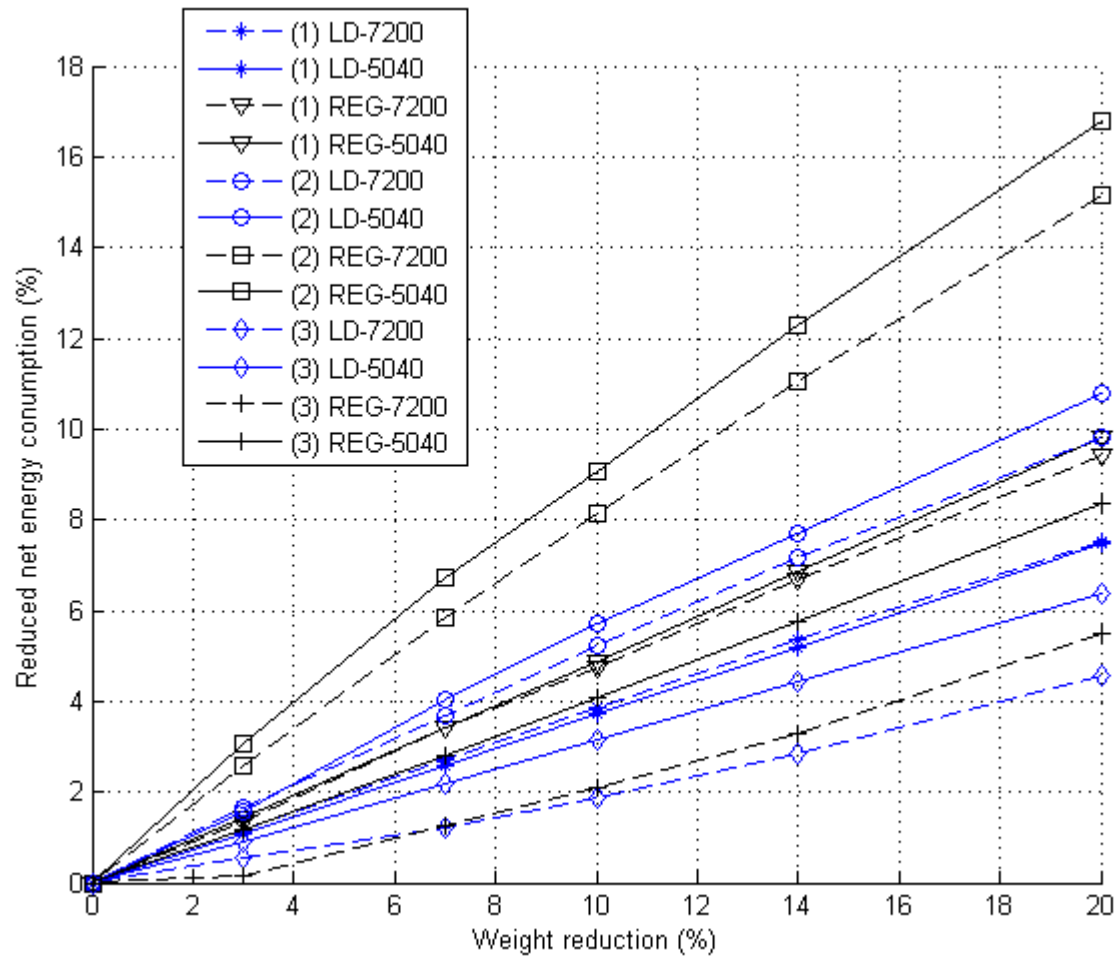
Summary:

- 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



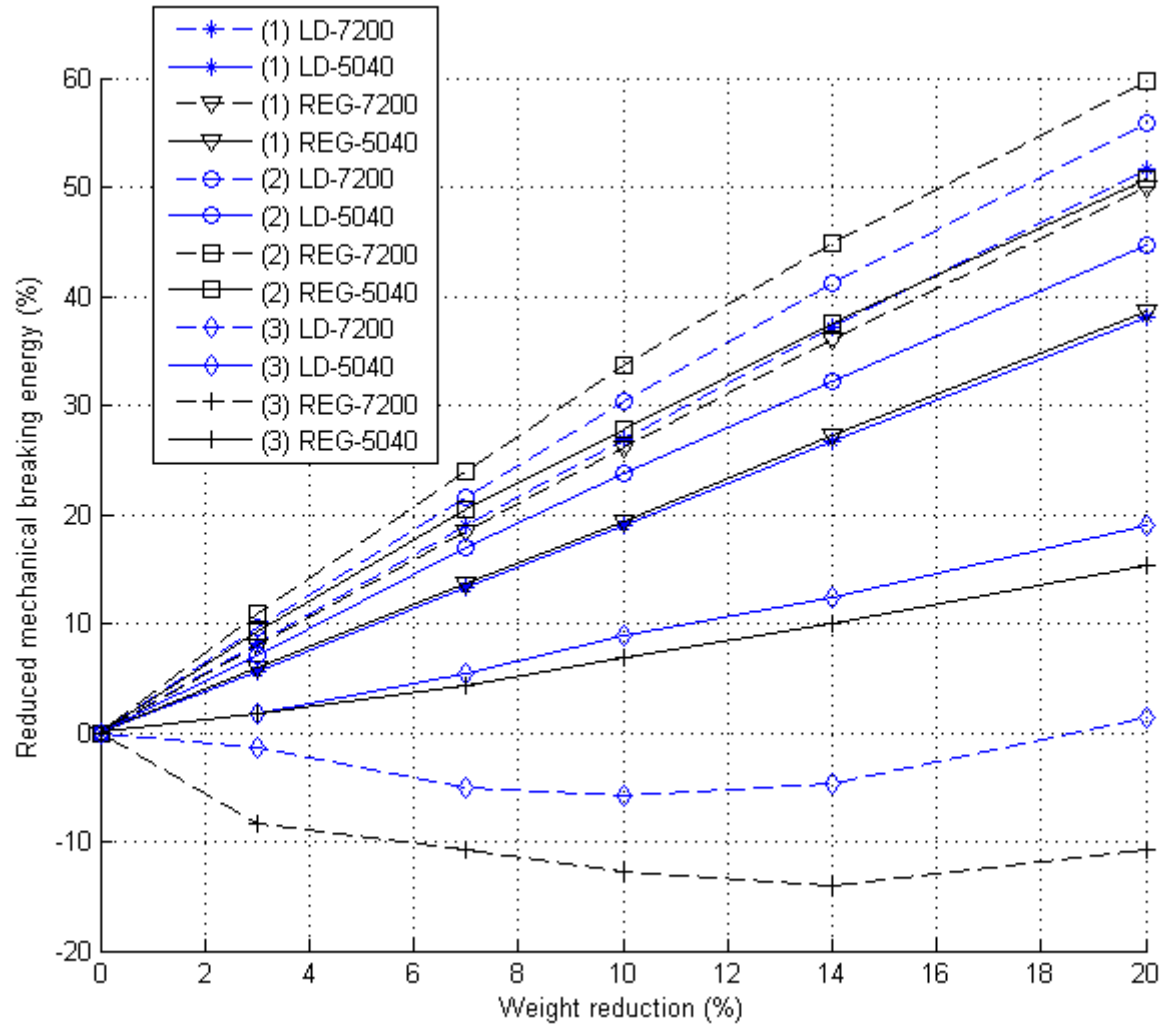
Results (scenario 1-3)

- Reduced net energy consumption

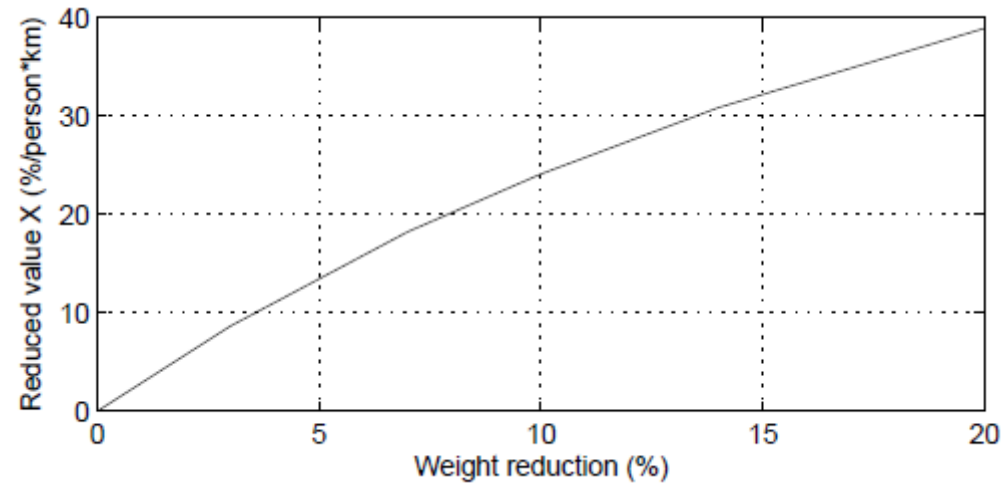


Results (scenario 1-3)

- Reduced mechanical breaking energy



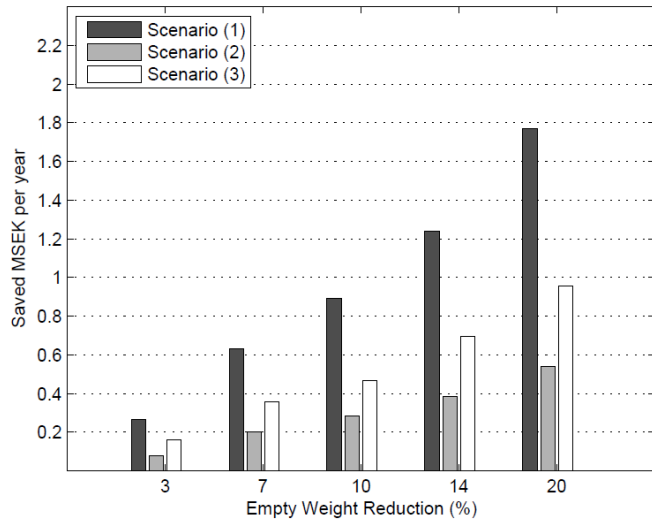
Results (scenario 4)



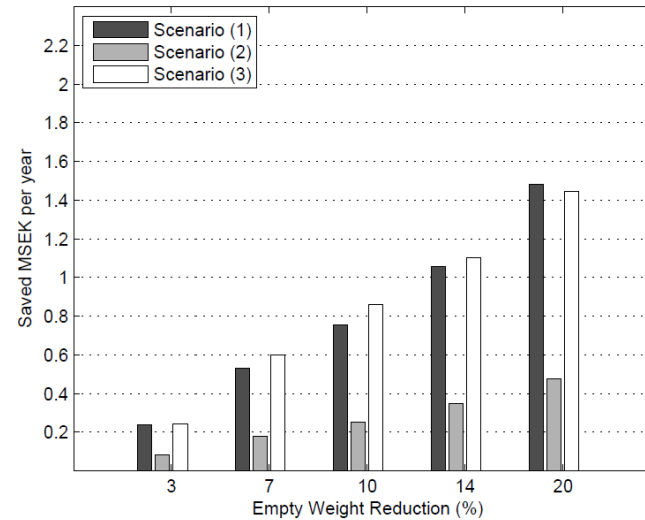
$$I_i = 1 - \frac{n_0}{n_{4,i}}$$

Number of seats

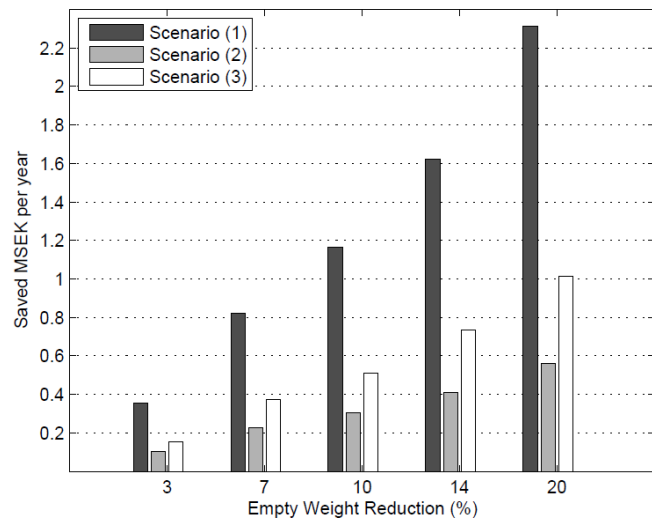
Results – cost savings / extra income



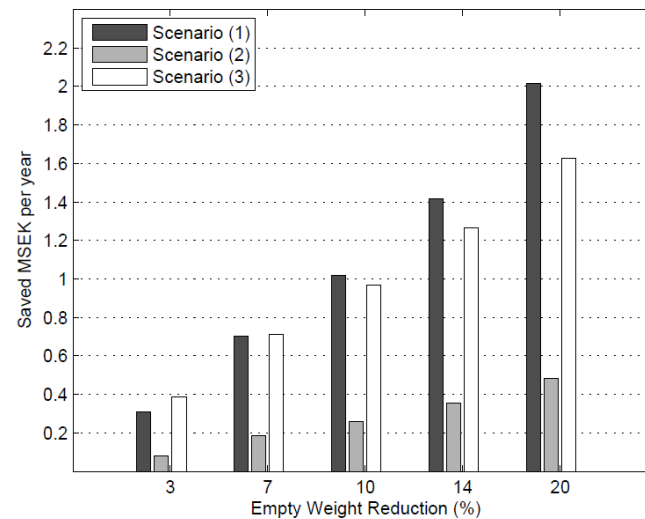
(a) LD 5040



(b) LD 7200



(c) REG 5040



(d) REG 7200

Considers *only* energy and brake wear



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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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Results – summary values

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Results – summary values

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Scenario 3	0.32	0.23	0.42	0.28
Scenario 4	1.93	1.93	1.93	1.93

Automotive	Aviation	Maritime
0.3 - 0.8	0.25 - 0.75	>1

Thank you for your attention!

Questions?



... research where ECOlogy & ECONomy meet

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