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Specification and verification of energy efficient rolling stock

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Motivation

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- Railways are the transport system with lowest specific energy consumption
- Other systems are becoming better!
- Railways: efforts needed to keep leading role

Situation in the Railway Industry

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Energy consumption

- is 4 ... 8% of total costs of a railway system
- can be about 50% of LCC of a locomotive
- is already addressed in contracts

But

- no common understanding about rules for definition and contracting between rolling stock manufacturers and different railway operators

➡ How to proceed in an appropriate way?

Situation in Other Industries

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- Aircraft industry:
  - Energy about 10 ... 35% of system costs (note: no taxes on fuel!)
  - Strong contracting and heavy penalties for non-compliance
  - e.g. based on lt / Seat*km

- Automobile industry:
  - Energy about 20 ... 30% of LCC (vehicle only)
  - Harmonised definition of load cycles „NEDC"
  - Customer awareness!

Automobiles

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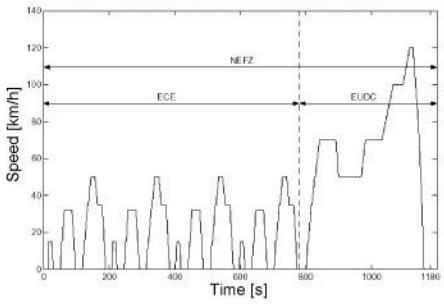
„New European Driving Cycle (NEDC)"



Case Study: Regional Train

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Motivation:

- Energy costs (capitalised) account for about 5% of the purchase prise of the whole train

Data of a hypothetical train:

Mass unloaded/loaded	150 t / 180 t
Power supply	AC 16.7 Hz, with regeneration
Max. speed	140 km/h
Max. tractive effort	200 kN
Max. power at wheel	2500 kW
Auxiliary power	50 kW (average)
Heating and comfort	not considered

Typical Load Cycle

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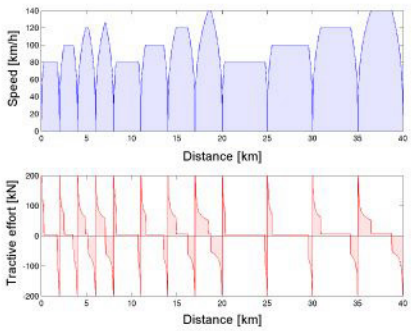

Typical Load Cycle (2)

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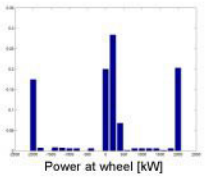
Histogram of power:
(assumption: acceleration and deceleration with 80% of available TE and power)



Consequences:

- Phases with high and low power
- Power flow in both directions (regeneration)
- For evaluation of energy consumption: detailled efficiency model for train necessary

Split of Energy Consumption

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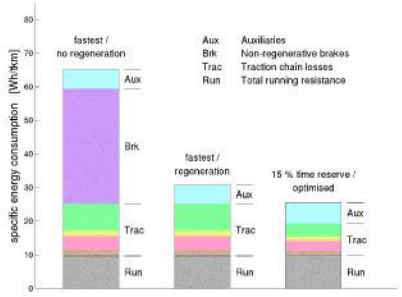

Influence Factors

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Main factors:

- Train mass
- Running resistance
- Losses in the traction equipment
- Consumption of the auxiliaries
- Availability and use of regenerative brake
- Economic driving style

All have to be considered adequately for:

- Design / optimisation of the train
- Writing of the specification
- Testing and evaluation of the results

Sensitivity Analysis

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Influence of some factors on energy consumption:

	∂E / ∂Factor
Train mass	0.84
Air drag	0.19
Transformer ohmic losses	0.22
Mean auxiliary power	0.19
Use of regenerative brake	-1.0
Time reserve + eco driving	-1.1

Interpretation:

- 10% increase in mass ➡ 8.4% higher consumption
- 50% less air drag 9.5% lower consumption
- only 50% use of regen. brake 50% higher consumption

Aspects of Verification (1)

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Load cycles:

- can be verified easily (energy and time can be measured precisely)
- are relevant in practice (other than e.g. a single efficiency value)

Constraints to be considered:

- Precise driving along a well defined trajectory
- Environment (rail surface, temperature)
- Repetition of tests to get average values
- Allow tolerances of 3 ... 5% in final result

NOTE: statements and values are based on experience of the authors with tests and measurements on real vehicles in earlier projects

Aspects of Verification (2)

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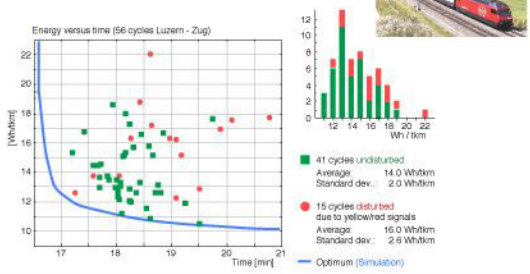
Example: influence of driving style
(simulation and measurement from earlier projects)



Different Types of Operation

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Load cycles (proposals):

High speed passenger train	Long distances, high speed
Interregio passenger train	Few stops, various speeds
Regional or suburban train	Many stops, fast acceleration *)
Short distance freight	Moderate speed, incl. shunting
Long distance freight	Long distances, various speeds
Freight in mountains	Incl. significant gradients up/down

Key value:

	„Energy index"	Wh / Seat*km	Wh / t*km
*)	Regio Train Example	22	30

Vehicles for Mixed Traffic

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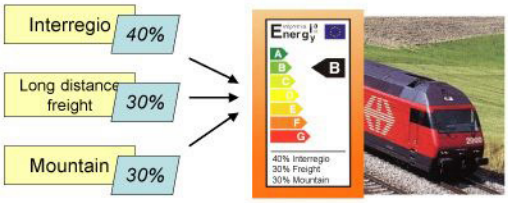
An energy index can be defined for mixed traffic:

- Useful e.g. for locomotives
- Keeps advantages of predefined load cycles



Conclusions

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- The definition of an „Energy Index" based on load cycles is suitable for railway vehicles
- This makes different offers transparent in view of LCC and bases contracts on realistic consumption
- A harmonisation or standardisation of the approach would be welcome