ECORailS –
Energy efficiency and environmental criteria in the awarding of regional rail transport vehicles and services

Deliverable 8:
Technological overview with regard to energy efficiency and environmental performance, ready to be integrated into the final Guidelines version

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Draft:	Function	Approval
Prof. Stefano Ricci	**Name**	
ULS	**Organisation**	
+39-06-44 58 51 44	**Phone**	
+39-06-44 58 51 44	**Fax**	
stefano.ricci@uniroma1.it	**E-Mail**	

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Energy efficiency and environmental criteria in the awarding of regional rail transport vehicles and services

Distribution:

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CB 3	Pro Rail Alliance	ApS	DE
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Contents

1. Catalogue description

1.1. Clusters and solutions selection

According to the first selection proposed by ULS and to the clusters selection agreed during the Copenhagen, Bergamo and Milan meetings, the technologies and Operational Measures included into this Deliverable are:

CLUSTER	SOLUTION
Optimisation of control functions	Control of comfort functions in parked trains
Energy recovery	On-board use of braking energy in diesel-electric stock
	Reversible DC substation
Energy storage	Braking energy recovering by super-capacitors on board equipment
	Braking energy recovering by super-capacitors in fixed installations
Train formation or typology	Multiple units (MUs) vs. loco-hauled trains
Reconditioning/revamping of vehicles that already exist	Re-engining of diesel stock / Upgrading of engines
Improvement of traction equipment efficiency	Optimisation of traction software
Eco-driving	Energy efficient driving by low-tech measures
Energy meters	Database of traction consumption
Management and organisation	LCC-driven procurement

<u>Cluster Optimisation of comfort functions</u>: This cluster includes all technologies concerning a new management of comfort functions oriented to avoid wasting electricity. The term “comfort functions” refers to those elements that are important for on-board people (passengers and personnel) like lighting system or system regulating the inner climate. The idea, on which these technologies are based, is adapting the energy consumptions to the different demand situations and avoiding the heat dispersions through the use of insulating materials.

<u>Cluster Energy recovery</u>: The breaking energy could be recovered and re-used by the same vehicle or by trains running on the same line. The final employments of the recovered energy are essentially two: traction purpose or auxiliary functions purpose.

<u>Cluster Energy storage</u>: The recovered energy (e.g. the braking energy) could be stored in several ways: on-board or in fixed installations. Different devices could be employed for this purpose like super-capacitors or batteries.

<u>Cluster Eco-driving:</u> In this cluster there are some measures that refer to energy efficient driving by studied driving strategies and eventually by driving advice systems. These solutions implicate a planned analysis of the characteristics of each line (altimetric and planimetric features, speed limits, distance between stops, etc) and of the recovery times in the timetable, the study of existing saving energy margins and then the definition of the most opportune driving strategies. Quite obviously, after this technical analysis, it is necessary to acquaint the drivers with the planned changes, to train them and often to stimulate them to do better.

Cluster Train formation or typology: This cluster includes all choices affecting the typology of the train, different combinations of components (e.g. bogies shared between two units) or, at an extreme case, the change of the whole traction system (e.g. magnetic levitation technology). Some choices refer to the particular shape of the car body (e.g. double-decked stock) to increase the seating capacity per train length leading to positive impact on energy efficiency and cost effectiveness by a minor weight per seat. A group of technologies in this cluster is related to different ways to compose a train by employing different kinds of vehicles or levering on the length of the train.

Cluster Reconditioning/revamping of vehicles that already exist: This cluster comprises some technical adjustments on already existing vehicles. In many cases, the high disposal costs and the elevated costs to acquire new rolling stock could justify changes on old fleets to reduce energy consumptions, noise and emissions. The actions on old trains can be substitutions of motors with more efficient ones (also unconventionally propelled motors), or their upgrading or substitution of other components (e.g. interior coach equipment, compressors …) that actually can be realized with better performances.

Cluster Improvement of traction equipment efficiency: This cluster represents different attempts to increase energy efficiency taking action directly on traction systems. Obviously the technologies mentioned here are very different from each other due to the different possible traction typologies. Therefore such solutions give rise to changes on motors or on electricity equipments (e.g. transformers), and on auxiliary traction equipments (e.g. their demand-controlled operation).

Cluster Energy meters: presents measures which consist of energy measurement by installation of energy meters in railway vehicles and/or in fixed installations and recording documentation. This solution provides consumption data for an exact energy billing system and for the assessment of energy saving measures (both technologies and operational measures) and their tuning (e.g. from consumption data it is possible to define changes about driving styles, operational measures in cluster M1).

The choice of solutions shown in this catalogue has been carried out looking at following criteria:

- best energy saving potentials
- large differentiation in terms of potential problems to be faced for implementation (e.g. investment dimension, legal constraints, safety or environmental risks, implementation time, traction systems, etc.)
- experience of already awarded technologies and operational measures
- applicability in WP4 pilot case studies
- representativeness across Clusters

1.2. Indicators and methodological approach for technologies and operational measures qualification

1.2.1. Energy savings potential

This item refers to the energy saving for a single vehicle. It has been estimated, by specifying a range of possible values (without using fixed values and fixed ranges) from worst to best case taking into account the different foreseeable application contexts.

The potentials estimates are based, on the evaluations already available in technical literature, on partners' expert judgments and on evaluations in previous projects (EVENT, TRAINER, Railenergy).

1.2.2. Pollutants emissions saving potential

This item refers to the pollutants emissions saving for a single vehicle. It has been estimated, by specifying a range of possible values (without using fixed values and fixed ranges) from worst to best case taking into account the different foreseeable application contexts.

The potentials estimates are based, on the evaluations already available in technical literature, on partners' expert judgments and on evaluations in previous projects (EVENT, TRAINER, Railenergy).

1.2.3. Economic potential

Economic potentials (on LCC basis) have been evaluated, as already presented in the Copenhagen meeting, by the following approach:

- Implementation Cost (IC): it represents the initial investment on board equipments and/or on infrastructure changes required by the technology or operational measure. The possible values of economic potentials are:
    - High: > 1 % of initial investment of the vehicle
    - Medium: 0.1 % ÷ 1 % of initial investment of the vehicle
    - Low: < 0.1 % of initial investment of the vehicle
- Operational Cost (OC): it is represented by vehicle running costs directly caused or influenced by the technology or operational measure (energy cost and costs for operating personnel)
    - Higher→in comparison to a situation without the technology/operational measure implementation
    - Similar→in comparison to a situation without the technology/operational measure implementation
    - Lower→in comparison to a situation without the technology/operational measure implementation

- Maintenance Cost (MC): this category includes all costs to repair failures and/or to prevent potential problems that could compromise operational service. These costs include materials and technical personnel costs.
    - High: > 1 % of initial investment of the vehicle
    - Medium: 0.1 % ÷ 1 % of initial investment of the vehicle
    - Low: < 0.1 % of initial investment of the vehicle
- Disposal Cost (DC): costs related to the end-of-life of technical equipment. This category includes demolition, disposal and selling off costs.
    - High: > 1 % of initial investment of the vehicle
    - Medium: 0.1 % ÷ 1 % of initial investment of the vehicle
    - Low: < 0.1 % of initial investment of the vehicle

1.2.4. Implementation time

The implementation is a global estimation of:

1. development time for the availability in the railway market
2. administrative time for the procedures to issue purchase orders to acquire specific equipments involved by a technology or by an operational measure; in particular it involves:
    - financial time→ availability of financial sources
    - technical→ procedures exploitation
    - legal→ integration into the set of regulations, (clarification of safety issues with Safety Authority and working rules with trade unions to be verified in advance)
    - management→ acceptance of environmental responsibility
3. construction time for the specific equipments involved by a technology or by an operational measure;
4. installation time to assembly the specific equipments.

The proposed ranges for total time horizon are:

- Short time: < 1 year
- Mid time: 1÷3 and 3÷5 years
- Long time: 5÷10 years
- Perspective: > 10 years.

This latter category should refer to those measures that are good solutions in general, but the guidelines should handle these measures separately, because these are not contributing to the general objective of ECORailS project.

2. Database Technological Records

2.1. Technology

2.1.1. Control of comfort functions in parked train

Cluster

Optimisation of comfort functions.

Description

Parked passenger trains are often heated all night. This consumes substantial amounts of energy. A possible solution is the development and implementation of an intelligent control tool for parked trains (e.g. pre-heating time of rolling stock as a function of external temperature, etc). Beside the installation of an automated controlled system, simple effective solutions include timers, manual control and instructions for maintenance and cleaning personnel.

Existing solutions mainly differ with respect to the following features:

- centralised control device for the entire train;
- possibility to operate lighting and heating at one third or half intensity;
- special programs for anti-freezing or preheating operation.

Advantages

Many railway companies apply control devices to reduce the energy demand during overnight standstill at a certain degree. Dynamic development of comfort functions control in parked trains is especially oriented in the field of Telematics control solutions. Some operators are reluctant to switch off heating in the night due to the danger of freezing and damage to equipment. Control of comfort functions in parked trains is applicable for electric DC, electric AC, diesel railway traction in passenger main lines, high speed, regional lines and suburban lines.

Success factors

- Assessment of current operation practice for standstill in order to identify possible measures and required functionalities of an automatic control tool.
- Motivation and incentives of cleaning personnel to collaborate in saving measures.
- Advanced control systems to avoid danger of freezing
- etc.

Disadvantages

The on-board equipment for controlling comfort functions is highly variable between vehicles. The heterogeneity of rolling stock makes the development of a generalized automatic control with big scale effects impossible. The coaches have to be warm when the trains are cleaned. However the time the cleaning personnel arrive may vary too much to program the timer in a way to take this into consideration. Due to low salaries the motivation of cleaning personnel to collaborate in such measures may be low.

Benchmark

According to different sources in countries of Central and Northern Europe energy consumption during standstill is up to 10 % of the total energy demand for train operation. In Mediterranean countries the share will be lower. It is a reasonable estimation to assume that this energy can be reduced by ~50 % by an intelligent control system. Therefore the saving potential per vehicle is about 2÷5 %. The Swedish railway operator SJ developed an automatic control (called PLC - Programmable Logistic Control) to tackle the problem. Compared to calculations made by SJ in the context of their introduction of the PLC system the operator estimated a saving potential of 15,000 kWh per year and coach. Given the total consumption for coach heating of about 55,000 kWh per year and coach, the measure is expected to save 20 to 30 % of the energy consumed for heating. The system optimises the use of electricity so that heat and light is minimized during parking hours, but automatically switched on well before service starts again. At the end of service the coach temperature is lowered to 12°C and raised again to service temperature one hour before service starts. The system is currently tested in a pilot project involving 4 coaches.

Reference list

[1] EVENT Project, “Evaluation of Energy Efficiency Technologies for Rolling Stock and Train Operation of Railways”, http://www.railway-energy.org/tfee/index

[2] TRAINER Project - TRAining programmes to INcrease Energy-efficiency by Railways (http://w3.disg.uniroma1.it/trainer/) (manual and video!)

[3] Christian Lauszat, Re-use of waste heat, Energy Efficiency Days 2009, in Tours/France

[4] Claus Doll, Fraunhofer-Institute Systems and Innovation Research, Michael Krail, University Karlsruhe, Institute for Economic Policy Research, Policy scenarios to meet Germany’s GHG reduction Targhets, NIAM / APRIL meeting ULC 8-9 ian.2009

[5] UIC CODE 345R Environmental specifications for new rolling stock, 2006, 1st edition, pp.21-22

INDICATORS	POTENTIALS	
Energy savings potential	In Mediterranean countries: 3-5 % In Northern countries: 4-9 %	
Pollutants emissions saving potential:	**Electric Traction**	**Diesel Traction**
CO_2 emission saving potential	depending on energy mix	In Mediterranean countries: 3-5 % In Northern countries: 4-9 %
NO_x emission saving potential	depending on energy mix	depending on the specific system more than the saving of energy
CO emission saving potential	depending on energy mix	depending on the specific system less than the saving of energy
HC emission saving potential	depending on energy mix	depending on the specific system less than the saving of energy
Particulate emission saving potential	depending on energy mix	depending on the specific system less than the saving of energy
Economic potential (on LCC basis):		
Implementation Cost (IC)	Low	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Low	
Implementation time:	**Description**	**years**
Development time	Status of development of Control of comfort functions in parked trains: in use	<1 year
Administrative time:		
○ Financial	This could be a bottleneck, depending on the given country.	<1 year
○ Technical	The needed know-how exists and is available. The installation of an automatic control tool is rather cheap as long as the rolling stock offers a convenient interface for such a system, e.g. a central control for the comfort functions. Especially in the field of Telematics control solutions, the technological development potential is still high, but it is easier to apply such solutions on new rolling stock	1 year
○ Legal	No legal process linked to the installation of on-board equipment for controlling comfort functions.	<1year
○ Management	A successful development and implementation of an automatic system for the control of comfort functions in parked trains has to be preceded by a thorough assessment of types of passenger coaches and operational practice in the treatment of parked trains. Energy meters equipment could be a powerful tool to improve the monitoring and communication of energy saving measures if they are in function or active to measure energy consumption during standstill.	<1 year
Construction time Installation time	Short to midterm (1 to 5 years), half of the time spent on construction and half for planning within the company.	<5 years
Total time		1-5 years

2.1.2. On-board use of braking energy in diesel-electric stock

Cluster

Energy recovery

Description

Modern diesel-electric vehicles can be equipped with the capacity to use some of the energy recovered during braking for auxiliary and comfort functions. In modern diesel-electric 3-phase locomotives the Diesel engine drives a generator feeding the DC link. The DC link feeds the traction inverters as well as the auxiliaries and the train bus supply. During braking, the traction motors feed the recovered power into the DC link. This additional power can either be converted into heat in braking resistors or used for other consumers, namely auxiliaries (compressors, ventilation etc.) or the train bus supply (supplying the comfort functions in passenger trains).The power management is usually performed as follows: the recovered braking power is fed into the DC link. The part of this power that can be used for auxiliaries or train bus supply is drawn from the DC link, the rest is dissipated in the resistors. The resistor is automatically switched on if the voltage in the DC link exceeds a certain limit value.

Reference list

[1] EVENT Project, “Evaluation of Energy Efficiency Technologies for Rolling Stock and Train Operation of Railways”, http://www.railway-energy.org/tfee/index

[2] www.railway-technical.com/locobloc.gif

[3] Lionginas LIUDVINAVICIUS, Leonas Povilas LINGAITIS “New Technical Solutions Of Using Rolling Stock Electrodynamical Braking”, TRANSPORT PROBLEMS (PROBLEMY TRANSPORTU) 2009, Volume 4 Issue 2 pp.23-35

[4] Philippe Barrade, Blaize Destraz, Alfred Rufer, Hybrid vehicle in railway applications: supercapacitive energy storage for diesel-electric locomotives, Laboratory of Industrial Electronics, STI-ISELEI, Swiss Federal Institute of Technology Lausanne, Switzerland

[5] Elena AGENJOS, Sergio VALERO, U. Miguel Hernandez, Antonio GABALDON, Mario ORTIZ Francisco G. FRANCO, Roque MOLINA Rafael J.GABALDON, “Energy Efficiency In Railways: Energy Storage And Electric Generation In Diesel Electric Locomotives “20th International Conference on Electricity Distribution Prague, 8-11 June 2009

[6] Steiner M., Scholten J., Energy Storage on Board of DC Fed Railway Vehicles, 35th IEEE PESC Conference, 21-24 June 2004, Aachen, Germany

INDICATORS	POTENTIALS	
Energy savings potential	2-5 %	
Pollutants emissions saving potential :		
CO_2 emission saving potential	2-5 %	
NO_x emission saving potential	2-5 %	
CO emission saving potential	2-5 %	
HC emission saving potential	2-5 %	
Particulate emission saving potential	2-5 %	
Economic potential (on LCC basis):		
Implementation Cost (IC)	Medium	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Low	
Implementation time:	**Description**	**years**
Development time	Status of development: in use	<1 year
Administrative time:		
○ Financial	This could be a bottleneck, depending on the country.	<1 year
○ Technical	The use of recovered braking energy for on-board purposes in diesel-electric stock is a very promising energy saving measure for passenger operation. There are virtually no additional costs and barriers. Diffusion is essentially limited by the speed of stock renewal. The feature is to be integrated into specification sheets in future purchasing of diesel-electric locomotives. The potential of the feature in DMU stock has to be assessed.	1 year
○ Legal	No legal process linked to the installation of the equipment to use braking energy in a diesel-electric stock.	<1 year
○ Management	On-board use of braking energy in the new rolling stock is a choice of the management policy linked with the renewed fleet and with environmental responsibility.	1-3 year
Construction time Installation time	The construction time for a new locomotive equipped for on board use of braking energy is similar to others.	<1 year
Total time		1-3 years

2.1.3. Braking energy recovering by super-capacitors on board equipment

Cluster

Energy storage

Description

By this technology it is possible to store the energy released when braking and use it during the next acceleration of the vehicle. Each time the vehicle brakes, the energy storage devices (super-capacitors) are loaded again. During the next acceleration the stored energy is released. This additional energy lowers current demands from the network, for the same traction effort.

Advantages

Charges in seconds. Double-layer capacitors compared with rechargeable batteries are extremely low internal resistance. Extremely low heating levels and improved safety. Good reversibility. High cycle efficiency (95 % or more). High output power. Little degradation over hundreds of thousands of cycles. Low impedance. Low toxicity of used materials. No danger of overcharge. Very high rates of charge and discharge. Virtually unlimited life cycle: millions of cycles, 10 to 12 year life.

Disadvantages

The amount of energy stored per weight unit (3 to 5 Wh/kg) considerably lower than an electrochemical battery (30 to 40 Wh/kg). About 1/10,000th the volumetric energy density of gasoline. The voltage varies with the energy stored. To effectively store and recover energy requires sophisticated electronic control and switching equipment. Highest dielectric absorption of all types of capacitors. Super capacitors and ultra capacitors are relatively expensive in terms of cost per watt.

Reference list

[1] M. Steiner, J. Scholten, “ Energy Storage on board of DC fed railway vehicles”, PESC 2004 Conference in Aachen, Germany

[2] M. Brenna, F. Foialdelli, E. Tironi, D. Zaninelli, “ Ultracapacitors application for Energy saving in subway transportation system”

[3] http://www.olino.org/wp-content/uploads/2009/03/bt-eco4-mitrac_energy_saver.pdf

[4] Philippe Barrade, Alfred Rufer, “The use of supercapacitors for energy storage in traction systems”, Laboratory of Industrial Electronics, STI-ISELEI Swiss Federal Institute of Technology Lausanne, Switzerland

[5] Philippe Barrade, Alfred Rufer, “High-Power Fast Energy Exchange between Storage Systems: Supercapacitors as energy buffer in transportation systems”, EVS-18: The 18th International Vehicle Symposium, 20-24 October 2009, International Congress Centre (ICC), Berlin, Germany

[6] Philippe Barrade, Alfred Rufer, “Current capability and power density of supercapacitors: considerations on energy efficiency”, EPE 2003: European Conference on Power Electronics and Applications, 2-4 September, Toulouse, France

[7] Philippe Barrade, “Energy storage and application with supercapacitors”, Laboratory of Industrial Electronics, STI-ISELEI Swiss Federal Institute of Technology Lausanne, Switzerland

[8] A. Schnewly, R. Gallay, “Properties and applications of supercapacitors – From the state-of-the-art to future trends”, PCIM2000 Power Quality, Nürnberg, Germany

[9] http://www.railway-energy.org/tfee/index.php?ID=210.

INDICATORS	POTENTIALS	
Energy savings potential	**Electric Traction**	**Diesel Traction**
	20-30 %	15-35 %
Pollutants emissions savings potential	**Electric Traction**	**Diesel Traction**
CO_2 emission saving potential	depending on energy mix	35 %
NO_x emission saving potential	depending on energy mix	depending on the specific system more than the saving of energy
CO emission saving potential	depending on energy mix	depending on the specific system less than the saving of energy
HC emission saving potential	depending on energy mix	depending on the specific system less than the saving of energy
Particulate emission saving potential	depending on energy mix	depending on the specific system less than the saving of energy
Economic potential (on LCC basis):		
Implementation Cost (IC)	Medium	
Operational Cost (OC)	Lower (decrease of 20 % for energy)	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Low	
Implementation time:	**Description**	**years**
Development time	Mature and reliable technology	<1 year
Administrative time:		
○ Financial	This could be a bottleneck, depending on the country.	<1 year
○ Technical	Applicability for railway segments: medium Type of traction: electric – DC, AC – diesel Type of transportation: passenger - regional lines, passenger - suburban lines.	1 year
○ Legal	No legal process linked to the installation of the equipment for use braking energy with super-capacitors.	<1 year
○ Management	Use of energy recovering braking energy by super-capacitors on board equipment is a choice of the management policy linked with the purchase of new rolling stock.	3-5 years
Construction time Installation time	The construction time for new locomotive equipped with recovering storage device with super-capacitors is the same as for other types of rolling stock	<1 year
Total time		3-5 years

2.1.4. Braking energy recovering by super-capacitors in fixed installation

Cluster

Energy storage

Description

During the braking phases some trains which are already in service and almost all new electric trains or locomotives are able to return energy to the overhead-line if this can receive it (e.g. when other trains are in traction phase and quite near to the braking train). In the regional transport case it is difficult to have at the same time a train absorbing power near to the braking one. For this reason the new energy storage technologies, such as super-capacitors, could be considered and collocated in fixed installations near stations where many trains stop. These trains or other can reuse the energy stored in their starting phase or other use of this energy could be done. A power supply optimisation system for storage in fixed installations can be installed in substations or along the track and it will operate on purely electrical basis.

Advantages

The highest energetic benefit of energy storage systems can be achieved in lines or in parts of the network:

- with a low degree of cross-linking due to the low probability of direct use of energy by other trains;
- in case of DC operation, because of the lower voltage of the Overhead Contact Line cause higher losses and reduce the effectiveness of the direct use by other trains;
- with slopes and high speeds due to high amounts of braking energy.

In contrast the lower energetic benefit of energy storage systems can be achieved in lines or in parts of the network:

- tightly meshed parts of the network with low speeds favour a direct interchange of braking energy
- in case of AC operation, because of the higher voltage of the overhead contact line cause less losses and make more effective the direct use of energy by other trains.

Disadvantages

The energy flows in the system are managed in a way that braking energy is stored only if no other train can use the energy directly. In other words there should be a clear hierarchy: a) direct use by other train, b) storage. An important issue is the layout of the storage system. Assuming a 50 t light rail vehicle and a maximum speed of 80 km/h, the critical energy is 3.4 kWh. There is a complex trade-off between technological and economic needs. On the one hand the storage unit should be dimensioned in such a way that it supplies enough energy and power for a train to accelerate without additional energy supply (e.g. to enable catenary-free operation over limited distances). On the other hand just the necessary storage capacity should be installed as storage systems cause relevant investment costs and imply additional weight. Furthermore, additional space is needed for storage equipment so that comfort or capacity for passengers may be negatively affected in some cases. The combination of both on board super capacitors and capacitors in fixed installations could be not advisable because the higher investment cost necessary in order to achieve higher efficiency of the storage could reduce the effectiveness of the singular storage systems (as they are fed by the same energy source). Problems with controlling the energy supply systems could rise.

Reference list

[1] A. Rufer, D. Hotellier, P. Barrade, “A Supercapacitor-Based Energy Storage Substation for Voltage Compensation in Weak Transportation Networks”, IEEE TRANSACTION ON POWER DELIVERERY, vol. 12, no.2, April 2004

[2] Markus Klohr, Christian Lauszat, Basic Storage components, Energy Efficiency Days, sept 24th 2009, in Tours/France;

[3] J. (Jens) Buurgaard Nielsen, H.P. (Huib) van Essen, L.C. (Eelco) den Boer, Tracks for saving energy, Energy saving options for NS Reizigers Delft, CE, July 2005 (Publication number: 05.4878.30 CE-publications are available from www.ce.nl)

[4] Philippe Barrade, Energy storage and application with supercapacitors, Laboratory of Industrial Electronics, STI-ISELEI Swiss Federal Institute of Technology Lausanne, Switzerland

INDICATORS	POTENTIALS	
Energy savings potential	**Electric Traction**	
	5-10 %	
Pollutants emissions saving potential:	**Electric Traction**	
CO_2 emission saving potential	depending on energy mix	
NO_x emission saving potential	depending on energy mix	
CO emission saving potential	depending on energy mix	
HC emission saving potential	depending on energy mix	
Particulate emission saving potential	depending on energy mix	
Economic potential (on LCC basis):		
Implementation Cost (IC)	High	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Medium	
Implementation time:	**Description**	**years**
Development time	Mature and reliable technology	<1 year
Administrative time:		
○ Financial	This could be a bottleneck, depending on the given country.	<1 year
○ Technical	Expected technological development is highly dynamic.	1 year
○ Legal	No legal process linked to the installation of the equipment for use braking energy with super-capacitors in rail infrastructure.	<1 year
○ Management	Use of energy recovering braking energy by super-capacitors in fixed installations is a choice of the management. It is dependent on the infrastructure development and on the recovering ability of already existing and future rolling stock.	<5 years
Construction time Installation time	The infrastructure construction time is important.	< 5 years
Total time		3÷5 years

Note: The values in the table have been calculated referring to a situation with one fixed installation having the capacity to recover contemporary the braking energy related to maximum 4 trains. Therefore the evaluation may be different depending on specific traffic near the fixed installation.

2.1.5. Reversible DC substation

Cluster

Energy recovery

Description

As above wrote, during the braking phases some trains which are already in service and almost all new electric trains or locomotives are able to return energy to the overhead-line if this can receive it (e.g. when other trains are in traction phase and quite near to the braking train). Energy not used by other trains can be recovered by reversible DC substations.

These substations, part of the fixed energy supply system, consist of a traction transformer, linked to the high voltage AC power supply grid, associated with a controlled traction AC/DC converter able to supply and recovery energy. Active filtering capability of the controlled AC/DC converter shall compensate network harmonics and reactive power.

Advantages

In addition to the braking energy recovery into the high voltage AC power supply grid this technology gives:

- Compensation of network harmonics re-injected by active filtering
- Compensation of reactive power
- Dynamic compensation of high voltage power supply fluctuations
- Limitation of power surges on the line
- Electronic fault protection (selectivity enhancement, reduction of electro-dynamic constraints, control of line overvoltage)
- Potential elimination of on-board braking resistors and DC circuit breakers in substations

Disadvantages

This solution has two different kind of possible disadvantages:

- a contractual complication because of PTA on the one hand has to negotiate a special agreement with the Infrastructure Manager, who usually have the responsibility to supply energy and own the plants, other side has to add some specific requirements for vehicles as electric energy at the pantograph during the service braking from specified initial speeds in the awarding procedures with TOCs or vehicles suppliers
- electric power supplier have to accept and believe true the declared technical performance of reversible DC substation respect to his grid in terms of:
    - harmonics
    - reactive power
    - power fluctuations and surges

Reference list

[1] Alstom advertising technical datasheet "Reversible dc supply substation HESOP^{TM} Harmonic & Energy Saving Optimizer"

[2] Railenergy Calculator, www.railenergy.eu/RailenergyMethology.aspx

INDICATORS	POTENTIALS	
Energy savings potential	**Electric Traction**	
	4-10 %	
Pollutants emissions saving potential:	**Electric Traction**	
CO_2 emission saving potential	depending on energy mix	
NO_x emission saving potential	depending on energy mix	
CO emission saving potential	depending on energy mix	
HC emission saving potential	depending on energy mix	
Particulate emission saving potential	depending on energy mix	
Economic potential (on LCC basis):		
Implementation Cost (IC)	High	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Low	
Implementation time:	**Description**	**years**
Development time	Mature and reliable technology, but implementation for 1500 V DC and 3000 V DC supply systems is under development.	<1 year
Administrative time:		
○ Financial	This could be a bottleneck, depending on the given country.	<1 year
○ Technical	The quality of the power returned to the power grid has to be assessed in the specific real operation.	1 year
○ Legal	No legal process linked to the installation of the equipment, but clear clauses between IM and Electric Energy Supplier about quality of the returned energy	<1 year
○ Management	The use of this technology for progressive renewal of already existing substations or in case of line extensions is a choice of the Infrastructure Manager. The potential is dependent on the infrastructure development and on the recovering ability of already existing and future rolling stock.	1÷3 years
Construction time Installation time	The infrastructure construction time is important.	1÷3 years
Total time		3÷5 years

2.1.6. Multiple units (MUs) vs. loco-hauled trains

Cluster

Train formation or typology

Description

The advent of modern power electronics and AC asynchronous traction motors has considerably reduced the volume of traction equipment. This (along with other technological developments) has facilitated the development of trains with decentralized traction, so-called electric multiple units (EMUs). A similar development has taken place in diesel traction called diesel multiple units (DMUs).

In today's regional railway transport some TOCs do not employ locomotives (e.g. in Germany, Sweden, Poland and Spain) but only MUs, as well as, on the contrary, other TOCs (e.g. Italy and Portugal) prefer to use available locomotives and coaches. Thus they aim at standardising their locomotive fleets and vary the composition of their trains.

The outcome of the comparison is indeed controversial when taking into account: the load factor; flexibility to adapt train length to varying demands (more flexibility for Loco-hauled trains – theoretically 1 coach variation is possible - but often less coupling efforts and less complicated vehicle logistics are involved by MUs provided of automatic coupling and self propelled capacity); the Life Cycle Cost, that usually is lower for MUs when the number of seats and the length of the train are limited; the possibility to change only the loco in a loco-hauled trains to up to date the performance of the traction systems to the future technological developments without changing all the train.

Advantages

Decentralised traction, by a better utilisation of wheel-rail adhesion since more axles are powered, raises maximum acceleration and deceleration rate, and allows efficient regenerative braking, that reduces also dust and wear of brake elements of friction. The higher the motor power and the more axles are powered, the more energy may be recovered.

Furthermore MUs allow a higher number of seats per train length ratio and a lower weight per seat. Furthermore the power installed on board is more or less proportional to the seats offered instead of the loco-hauled trains where the on board power is ever the same loco power and this cause decay of engine utilisation.

There is a clear energy advantage of MUs over loco-hauled trains.

As far as flexibility issues are concerned a comparison between MUs and loco-hauled trains is much more difficult to establish, but experience from several operators shows that short MUs stock with automatic coupling shows the best flexibility in everyday operation.

Disadvantages

In the choice of MUs it has to take into account many issues (included organisational features of the TOC, its availability of regional transport coaches and their conditions) but the constraint to change the whole train set in order to improve the performance of the traction systems could be seen as a clear disadvantage. A loco gives also the flexibility to haul both double and single deck coaches.

An additional disadvantage is that most MU designs do not allow the transfer of passengers or stuff between the units when moving.

Benchmark

In the table below there is a brief overview related to the weight per seat of some train configuration available in the market.

Type of vehicles	Type of service	number of bodies	weight per seat [t/seat]
EMU	Regional	2	0,68-0,54
EMU	Regional	3	0,73-0,51
EMU	Suburban	3	0,58-0,45
EMU	Regional	4	0,64-0,46
EMU	Regional	5	0,53-0,48
DMU	Regional	1	0,78-0,56
DMU	Regional	2	0,70-0,44
Tilting DMU	Regional	2	0,78-0,70
DMU	Regional	3	0,60-0,52
coach (c.)	Regional	1	0,37-0,35
driving coach (d.c.)	Regional	1	0,61-0,42
loco-hauled train	Regional	5c.+ 1d.c.+ 1loco	0,76-0,66
loco-hauled train	Regional	4c.+ 1d.c.+ 1loco	0,81-0,71
loco-hauled train	Regional	3c.+ 1d.c.+ 1loco	0,88-0,78
loco-hauled train and double-deck coaches	Regional	5c.+ 1d.c.+ 1loco	0,67-0,45

Reference list

[1] EVENT Project, “Evaluation of Energy Efficiency Technologies for Rolling Stock and Train Operation of Railways”, http://www.railway-energy.org/tfee/index

[2] http://www.arinc.com/products/rail_control_ctr/index.html

INDICATORS	POTENTIALS	
Energy savings potential	5-10 %	
Pollutants emissions saving potential:	**Electric Traction**	**Diesel Traction**
CO_2 emission saving potential	depending on energy mix	5-10 %
NO_x emission saving potential	depending on energy mix	5-10 %
CO emission saving potential	depending on energy mix	5-10 %
HC emission saving potential	depending on energy mix	5-10 %
Particulate emission saving potential	depending on energy mix	5-10 %
Economic potential (on LCC basis):		
Implementation Cost (IC)	Low	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Low	
Implementation time:	**Description**	**years**
○ Development time	Existing technology; some time is needed for the procurement process.	<1 year
○ Administrative time:		
○ Financial	This could be a bottleneck, depending on the given country.	0 years (ideally)
○ Technical	The needed know-how exists and is available.	0 years
○ Legal	No legal process must be linked to the adoption of this technology.	0 years
○ Management	This could be the main bottleneck.	0 years (ideally)
○ Construction time ○ Installation time	The time spent on construction is the same as for other types of rolling stock.	<1 years (ideally)
Total time		<1 year

2.1.7. Re-engining of diesel stock / Upgrading of engines

Cluster

Reconditioning / revamping of vehicles that already exist.

Description

Rolling stock can be used intensively for 25 to 40 years. With advancing age, however, the maintenance costs increase, fuel consumption rises in comparison with more modern locomotives, and performances decrease.

In such situations, the option of revamping an asset with a modern power unit is in many cases an economical alternative to procuring a new locomotive. Compared with older engines, the power-to-weight ratio of new engines is usually substantially better. Additionally, new engines fulfil actual exhaust emission standards and thus the re-engining will contribute to improved air quality. A new locomotive costs a lot of money, but replacing an engine is far more than a mere removal and refitting operation as the components and interfaces on the old locomotive will be fundamentally different from those on an engine which is 20 or 30 years younger.

On average re-engining costs roughly 60 % of the price of a new locomotive but extends the longevity of the asset by as much as its original life expectancy. Experience shows that the investment can pay for itself in two to four years and brings a financial return in the long term.

As part of the very first preparations for an engine replacement, the economic viability based on a detailed study of the market must be analysed. The decisive requirement is that the vehicle is basically sound. Load-bearing components, structural components as body, bogies, etc. must have a residual strength referring to the estimated residual life after the re-engining that have to comply with the original design provisions in order to maintain the validity of the authorisation by the National Safety Authority.

Other issues for re-engining of a diesel locomotive refer to:

- With diesel-hydraulic locomotives, the transmission should be in a sufficiently good enough condition to be reconditioned or converted.

- With diesel-electric locomotives the old generator has to be examined to see if it can be modified to suit the requirements of the new engine or needs to be completely replaced.

- With both the matching up of the interfaces, concerning vibration characteristics, as well as locomotive and engine data, taking into account the future operating conditions such as altitude, air humidity, intake air temperature, speed profile.

The legislative file of Non-Road Mobile Machinery (NRMM) contains today 4 directives: the "mother" Directive 97/68/EC, the amendments Directive 2002/88/EC and Directive 2004/26/EC, and the last amendment Directive 2006/105/EC:

The amended NRMM Directive requires that any existing traction units that are re-engined in the future shall be fitted with new engines that meet either the Stage III a or Stage III b limits values.

Benchmark

Deutsche Bahn, for instance, repowered 400 V290 multipurpose locomotives with the 1,000-kilowatt 8V 4000 unit. And 160 British HST (high-speed train) power cars that have been in daily use since 1976 have been given new Type 16V 4000 R41R engines.

In Thailand, the national railway is upgrading its 20-year-old Alstom locomotives with MTU 16V 4000 diesel traction units (1,700 kilowatts).

They will reduce fuel consumption by more than 28 percent. Other deciding factors for the award of the contract were the performance and availability of the engines. The Swedish logistics provider Green Cargo is refitting 62 Bombardier T44 diesel locomotives with Type 12V 4000 R43 PowerModules in a program to be completed by 2011.

Advantages

- Lower investment costs in comparison to new acquisitions and increased economic value of the vehicle
- Reduced consumption values and operating and maintenance costs
- Shorter maintenance times
- Longer duty periods
- Greater availability, reliability and availability
- Electronic detection of operating status
- Shorter idle times
- Ecologically friendly with low consumption and reduced exhaust emissions.

Reference list:

[1]. MTU Report 03/09, www.mtu-online.com

[2]. www.bombardier.com, reports

[3]. www.uic.org/IMG/pdf/060912_Rail_Diesel_8aout_06.pdf

[4]. http://ec.europa.eu/enterprise/sectors/mechanical/documents/legislation/emissions-non-road/

INDICATORS	POTENTIALS	
Energy savings potential	>10 %	
Pollutants emissions saving potential:		
CO_2 emission saving potential	>10 %	
NO_x emission saving potential	20-85 %	
CO emission saving potential	practically unchanged	
HC emission saving potential	20-75 %	
Particulate emission saving potential	up to 90 %	
Economic potential (on LCC basis):		
Implementation Cost (IC)	High	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Low	
Implementation time:		
Development time	Re-engining of old diesel stock is common practice today.	0 years
Administrative time:		
○ Financial	This could be a bottleneck, depending on the given country. On average it costs roughly 60 % of the price of a new locomotive.	<1 year (ideally)
○ Technical	The know-how exists and is available. Once the decision to repower has been taken, it must determine the as-is situation as part of the technical project planning that follows. They match up the interfaces, the locomotive data and the engine data.	<1 year
○ Legal	The legislative file of Non-Road Mobile Machinery (NRMM) must be applied but it is available.	<1 year
○ Management	This is the main bottleneck besides financial sources.	0 years (ideally)
Construction time Installation time	The time strongly depends of the supplier. Additional time is needed to analyze the stage of locomotive.	1-3 years
Total time		1-3 years

2.1.8. Optimisation of traction software

Cluster

Improvement of traction equipment efficiency

Description

In modern electric stock, various components of the power train are regulated and operated by an on-board computer. In some trains a Train Control and Management System (TCMS) is available.

The TCMS controls and/or supervises the following systems in the train:

- Air Supply System
- APC System
- ATP System
- Automatic Couplers
- Auxiliary Electric System
- Battery System
- Brake System
- Driver's Safety Device
- Exterior Doors
- Fire Detection System
- Heating and Ventilation Air Conditioning System
- High Voltage System
- Interior Doors
- Interior Lighting
- Passenger Information System
- Propulsion System
- Toilets

The TCMS also handles the interface to the driver, crew, and service personnel. The buttons, switches, indicators and other gear on the driver's desk are connected to the TCMS. The TCMS translates the operator's actions into control signals to the various systems and reports back to the operator via the indicators.

The corresponding software is fixed by the manufacturer and usually not modified by the railway operator. In many cases the corresponding software offers considerable potential for optimisation from an energetic point of view.

In this case a tuning of existing software, in co-operation with manufacturers, in the delivery phase or after an operational period, is an interesting option. The principle consists in changing the setpoints of inverter control according to the specific service profile and the value of other parameters such as catenary voltage, wheel-track conditions or speed. This includes optimising the setpoints of the following quantities:

- Voltage in DC link
- Magnetic flux in motor
- Pulse frequency of rectifier and traction inverter
- Pulse pattern in traction inverter

All the target values of these quantities have to be optimised at the same time. Virtually all constant (as opposed to power dependent) losses in the inverters depend quadratically on DC link voltage. The reduction of this voltage during low load periods and/or standstill therefore cuts energy consumption to a considerable extent.

About hardware equipments, the computing capacity installed on older locomotives is sometimes not sufficient to implement additional features. Since propulsion software is a real-time application, any modification slowing down the system too much may lead to bad functionalities in propulsion. Therefore this solution is applicable to those vehicles where there is the possibility to tune the software.

In principle, most locomotives and MUs of all power classes can be optimised. However, it has to be examined for each vehicle series to what degree the software is optimised already.

Experts calculate a theoretical saving potential of 15 % achievable through traction software measures. In practice, an ex post software improvement will typically raise energy efficiency by 1-3 % depending on vehicle and the degree of software optimisation already realised by the manufacturer. For large series even a small improvement potential of only 1 % can economically justify such a measure.

A software optimisation of the power train of existing stock will in many cases offer appreciable potential for energy savings. The feasibility and profitability of such a measure is to be assessed individually by experts.

When purchasing new stock, the degree of optimisation should be evaluated. Generally large series are the most interesting candidates.

Reference list:

[1]. www.bombardier.com, reports

[2]. www.uic.org/IMG/pdf/060912_Rail_Diesel_8aout_06.pdf

[3]. http://ec.europa.eu/enterprise/sectors/mechanical/documents/legislation/emissions-non-road/

[4]. AIM® flexible, custom dispatch and SCADA solutions for Rail System Integration www.arinc.com/downloads/.../railsystemsintegration-slipsheet-view.pdf

[5]. http://www.railway-energy.org

INDICATORS	POTENTIALS	
Energy savings potential	1-3 %	
Pollutants emissions saving potential:		
CO_2 emission saving potential	depending on energy mix	
NO_x emission saving potential	depending on energy mix	
CO emission saving potential	depending on energy mix	
HC emission saving potential	depending on energy mix	
Particulate emission saving potential	depending on energy mix	
Economic potential (on LCC basis):		
Implementation Cost (IC)	Low	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Low	
Implementation time:		
Development time	The technology for optimisation of traction software exists thus development time can be taken as quasi zero.	<1 year
Administrative time:		
○ Financial	The financial resources needed for the installation of upgraded software are usually not significant by comparison with the new software. It shall not be a barrier to implementation.	<1 year
○ Technical	The needed know-how exists and is generally available for new or still produced stock.	<1 year
○ Legal	Some software logical rules (e.g. emergency braking intervention,…) issues have to comply to standards. Clarification of safety issues with Safety Authority are to be verified in advance.	<1 year
○ Management	After a clear decision from the top management the time needed in this context is negligible.	<1 year
○ Construction time	The technology exists thus construction time can also be taken as quasi zero.	<1 year
○ Installation time	Installation time is only function of the number of vehicles to be upgraded.	<1 year
Total time		<1 year

2.2. Operational Measure

2.2.1. Energy efficient driving by low-tech measures

Cluster

Eco-driving.

Description

In view of the barriers impeding a fast diffusion of advanced driving advice systems, non-technological short time efforts to promote energy efficient driving are especially promising. Many measures including training programmes for drivers can be implemented at good cost-benefit ratio and virtually do not meet any barriers. A considerable part of the reduction potential offered by energy efficient driving might be exploited by non-technological or low-tech measures (databases, systems based on GSM-R, laptop technology, etc). The following driving styles for energy efficient driving can be applied: cruising (DSB strategy) or coasting (French drivers strategy) [6], reducing maximum speed, using valleys and hills. The driving strategy depends also on the power on board of the train [7] (for coasting strategy it is advisable to have more power available).

Benchmark

DSB (Danish State Railway) decided to implement in all rolling stock by 2011 a system that handles all information required to do the mathematical calculations necessary to arrive on time and save energy, such as position, timetable and speed limitations. This means that the driver can better focus on safety related aspects1. A detailed report has been produced in DSB to determine the potential energy savings by introducing this system in Denmark. By conducting a series of tests and analyzing the results, the report states that DSB will save up to 15 % on the traction energy while improving punctuality.

Reference list

[1] TRAINER Project - TRAining programmes to INcrease Energy-efficiency by Railways (http://w3.disg.uniroma1.it/trainer/) (manual and video!)

[2] UK – National Express is embarking on a program of 'eco train driving'. As part of an integrated two-year programme to save energy and reduce CO2 output, all National Express drivers are being assessed for energy efficient driving techniques. National Express believes that up to 6 % of energy can be saved in this area. (http://www.nationalexpresseastanglia.com/about_us/energy_efficient_travel)

[3] Implemented: DB (all 14.000 drivers qualified; theory, training simulator and coaching tips)

[1] This view is not shared by some National Safety Authorities that think that the driver could become inattentive when following the system indication about the speed because it could be different from the speed indicated by the safety systems as the signalling systems.

[4] Howlett PG, Milroy IP, Pudney PJ: Energy-efficient Train Control; Control Engineering Practice, Volume: 2 Issue: 2 Pages: 193-200 Published: APR 1994, ISSN: 0967-0661

[5] Lee, C.-K. (1999): A Simulation Study on the Energy Saving Strategy of Train Operation. Proceedings of the World Congress of Railway Research WCRR 99, Tokyo, 1999.

[6] D. Vastel, "SNCF Energy Savings Program", Energy Efficiency Days, September 24th, 2009

[7] H. Rohrer, "Impatto dello stile di guida e della programmazione dell'orario sul consumo energetico", Conference Per un uso attento dell'energia nel trasporto su ferro, Milan, 25 January 2010

INDICATORS	POTENTIALS	
Energy savings potential	**Electric Traction**	**Diesel Traction**
	5-10 %	5-10 %
Pollutants emissions saving potential:	**Electric Traction**	**Diesel Traction**
CO_2 emission saving potential	depending on energy mix	5-10 %
NO_x emission saving potential	depending on energy mix	5-10 %
CO emission saving potential	depending on energy mix	5-10 %
HC emission saving potential	depending on energy mix	5-10 %
Particulate emission saving potential	depending on energy mix	5-10 %
Economic potential (on LCC basis):		
Implementation Cost (IC)	Low	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Low	
Implementation time:	**Description**	**years**
Development time	The needed sources exist for the implementation of the programme. Thus the time need for this is quasi zero.	<1 year
Administrative time:		
○ Financial	This could be a bottleneck (depending on: the given country; on the specific on-board technologies needed and on the availability of suitable fixed technologies).	<1 year
○ Technical	The needed know-how exists and is available	<1 year
○ Legal	No legal process linked to the adoption of such measures. Working rules and clarification of safety issues in the driver's desk with Safety Authority to be verified in advance.	<1 year
○ Management	This is the main bottleneck	<1 year
Construction time Installation time	Ideally less than 1 year, half of the time spent on construction (i.e. planning within the company), the remaining half on installation (i.e. carrying out the training itself).	<1 year
Total time		< 1 year

2.2.2. Database of traction consumption

Cluster

Energy meters

Description

Energy meters provide accurate energy consumption data of train runs. This is a very promising means to create an economic incentive for operators to save energy. At the same time, monitoring of energy saving measures is considerably improved. Experience from DB AG demonstrates that a quick roll-out is both technically and economically feasible.

Diesel flow meters provide real time information on the fuel consumption in diesel traction. Compared to energy meters for electric traction, benefits are less. However, an improved monitoring of fuel economy of diesel stock as well as a raised energy awareness of drivers justifies the introduction of diesel metering equipment. Furthermore, in case of diesel traction, external costs related to the emission of pollutants have a higher relevance.

Energy saving have high relevance also in case of electric traction, but often access fees don't take into account the real amount of energy consumed. Furthermore, the infrastructure manager (IM) often bears the real energy costs instead of the TOC or the PTA.

Energy meters can be used for:

- billing purposes (reference time of 5 minutes) in order to calculate the real energy consumption of each TOC and let them pay what they really consume;
- saving purposes, which implies functioning in real time (reference time of about 30 s) and possibility to exchange information with ground equipments able to send information to the driver in order to optimise the driving parameters by comparing the actual data of consumption with reference values for that position along the line.

TSI and CENELEC rules will impose the requirements for the energy meters and their accuracy (about 2 % for those available in the market) levels (see D7 Fig. 5-3 and D7 Fig. 5-4).

Data recording: a memory is needed to avoid data loss in case the regular read-out is not possible. Usually, 60 days of data storage will in most cases be sufficient.

Remote reading: a remote reading by GSM or GSM-R radio link improves the efficiency of the process.

The rolling stock department of the French SNCF recommends not creating sub-parks equipped with energy meters within traction unit series to keep an easier maintenance of traction units [1].

The installation of energy meters in railway vehicles provides consumption data that could be used for the identification and assessment of energy saving of technologies and operational measures adopted.

Data recording could be used to set incentives for drivers as foreseen many years ago for drivers of the steam loco.

A complete database of traction consumption should include, where possible, the following record per each line, per each direction, per each train:

- Energy consumption (kWh)
- Offered capacity (number of seats)
- Satisfied demand (number of passengers)
- Length of the line (each direction) (km)
- KPI2: Energy consumption per offered capacity (kWh or l / seat km)
- KPI4: Energy consumption per satisfied demand (kWh or l / pass. km)
- Characteristics of the train (cfr. D7 paragraph 3.2)
- Length and weight (train fully equipped for service operation without passengers on board)
- Characteristics and conditions of the line (cfr. D7 paragraph 3.2)
- Environmental conditions (cfr. D7 paragraph 3.2)
- Comfort parameters (cfr. D7 paragraph 3.2)
- Foreseen operational features (cfr. D7 paragraph 3.2)
- Real timetable

Benchmark

In 2000 DB Energie tested the installation of energy meters in several trains as well as data transmission and evaluation in the TEMA project. The meters measure both energy intake and recuperation energy. At DB AG, energy metering is seen as an essential prerequisite for determining the influencing factors for energy consumption and monitoring the success of energy saving measures. Within the project different types of measuring devices tailored to individual vehicle series were installed and tested. The devices have a minimum accuracy of 1 %. The system calculates and records 5 or 15 min consumption profiles. Remote reading via GSM is implemented. Energy meters have now been incorporated into the specifications of new stock. A roll-out into the DB fleet is currently realised. DB AG has introduced exact energy billing based on energy metering since 2003. (www.rail-energy.org).

NSB AS (Norwegian State Railways) has reduced their electric energy consumption per gross tonne kilometre with almost 20 % since 2004. With the introduction of ERESS, advanced energy measuring systems and consisted railway energy settlement and billing have been established. NSB has therefore been able to realise the energy cost reductions of their energy management and saving initiatives. (The interest in the Nordic solution for measurement and settlement of energy consumption cost for trains has been significant in several European countries. This summer the Belgian Infrastructure Manager, Infrabel, joined the Nordic partnership. In addition the French train company SNCF is running a test version of the system. ERESS is also developing a common European solution for validating, splitting and distribution of energy measurement data for the International Union of Railways UIC [2]).

RFF (French IM) imposed traction units' equipment with energy meters starting on the 1st of January 2010 [1].

The Direction Committee of SNCB/NMBS (Belgian TOC) agreed on May 5th 2009 to install on board Energy Metering Systems on all new Traction Units. The accuracy shall be in compliance with the Conventional Rail Locomotives and Passenger Rolling Stock TSI in approval (CR loc&pas TSI). After approval of TSI, the conformance shall be tested by a Notified Body.

SNCB/NMBS will use the existing ATLAS (EBI star and ground from Bombardier) to store the data on board and transmit the data to ground. Infrabel (Belgian IM) will order an external audit to check the integrity on this data flow. The ground server of ATLAS will transfer the data format to the UTIL-TS messages defined in the UIC-leaflet 930. Infrabel shall use the recorded consumption starting from January 2011. A coefficient will be added to take into account the losses in the substations and on the Overhead Contact Line.

Reference list

[1] D. Vastel, "SNCF Energy Savings Program", Energy Efficiency Days, September 24th, 2009
[2] http://www.nress.org/

INDICATORS	POTENTIALS	
Energy savings potential	**Electric Traction**	**Diesel Traction**
	5-15 %	5-15 %
Pollutants emissions saving potential:	**Electric Traction**	**Diesel Traction**
CO_2 emission saving potential	depending on energy mix	5-15 %
NO_x emission saving potential	depending on energy mix	5-15 %
CO emission saving potential	depending on energy mix	5-15 %
HC emission saving potential	depending on energy mix	5-15 %
Particulate emission saving potential	depending on energy mix	5-15 %
Economic potential (on LCC basis):		
Implementation Cost (IC)	Low	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	None	
Implementation time:	**Description**	**years**
Development time	The technology exists thus development time can be taken as quasi zero.	0 years
Administrative time:		
○ Financial	The financial resources needed for the installation of energy meters are very limited. They should not be a barrier to implementation.	<1 year
○ Technical	The needed know-how exists and is available.	0 years
○ Legal	To define a protocol for using this measurement and documentation may need some months.	<1 year
○ Management	After a clear decision from the top management the time needed in this context is negligible.	<1 year
Construction time Installation time	The technology exists thus construction time can also be taken as quasi zero. If and when financial hurdles are overcome, installation time is only the function of the number of energy meters to be installed (and consequently depends on the size of the fleet).	1-3 years
Total time		1-3 years

2.2.3. LCC driven procurement

Cluster

Management and organisation

Description

An increased role of LCC in railway purchasing decisions is one of the key success factors for a rapid diffusion of innovative technologies for energy efficiency. At the same time, in a cost perspective focusing on the whole company rather than individual departments or sub-companies, a more LCC-driven procurement could make a valuable contribution to cost efficiency. Success factors are bonus rules in procurement contracts or better verification of LCC guarantees and foreseen penalty clauses for the case of non-compliance.

Barriers are high and are mainly concerned with the high degree of cost segmentation within railways and the lack of corresponding financial interfaces between individual departments. In view of the clear win-win situation for the environmental and economic performance of both railways and industry, the issue should be given high priority.

There is no canonical and standardized LCC concept for rail vehicles. Some LCC calculations include at least costs for operation personnel, downtimes, disposal.

LCC for rail vehicles

	Locomotive for passenger service*	**Locomotive for freight service***	**High-speed train (ICE 3)****
Investment	22.7 %	11.7 %	80.8 %
Energy	46.2 %	73.8 %	7.8 %
Maintenance	31.0 %	14.4 %	11.4 %

Source: * Trümpi 1998 ** Ernst 2001

The data in the table above are taken from different sources and are based on different assumptions (interest rates, energy costs, useful life, etc.).

While being theoretically the most complete cost indicator, LCC is difficult to handle and cannot be given in a general and straightforward manner. The reason is its strong dependence on operational conditions, which vary between operators and may not be predictable for the future. Therefore it is very important to take into account also the adoption of a monitoring system for energy consumption (see D7 for measurement and monitoring of energy consumption to keep of the contract) and the other costs (maintenance costs, operational costs, disposal costs). A reference could be what has been already done for the Reliability, Availability, Maintainability indicators.

Even if it could be very useful to have implemented the already described operational measure "Database of traction consumption", it is possible to start anyway with a LCC driven procurement without this implementation.

A simplified Cost Benefit Analysis could be performed to evaluate the offers on the basis of the declared values, by the applicants to the bid, for the following potentials, direct and specific indicators (on a LCC basis) related to the proposed technologies or operational measures and as described in D7:

- energy consumption Key Performance Indicators:
  - KPI2: Energy consumption per offered capacity (kWh or l / seat km)
  - KPI4: Energy consumption per satisfied demand (kWh or l / pass. km)
  - Added implementation cost as a % of the initial investment of the vehicle/service (the initial investment for onboard equipments and/or for infrastructure changes required by the solution is to be considered)
  - Added operational cost (vehicle running costs, directly caused or influenced by solution implementation, excluding energy) as a % of the initial investment of the vehicle/service, in comparison with a situation without solution implementation
  - Added maintenance cost (all kinds of cost, directly caused or influenced by solution implementation, to repair failures and/or to prevent potential problems that could compromise operational service; they include materials and technical personnel costs) as a % of the initial investment of the vehicle/service
  - Added disposal cost (costs, directly caused or influenced by solution implementation, related to the end-of-life of technical equipment; it includes demolition, disposal and selling off costs) as a % of the initial investment of the vehicle/service
  - Energy and emission saving potentials, for a single vehicle/service in %, directly related to the solution implementation
- Useful life of the vehicle.

In any case the PTA or TOC have to specify all the characteristics and conditions defined in paragraph 3.2 of D7 and apply the monitoring system evaluating the keeping of the contract described in D7 paragraph 5.5. Furthermore they have to know the following general data:

- Annual average running distance for each vehicle
- Railway specific energy mix of the line or the network involved (for the external costs evaluation due to the pollutant emission related to the electric traction)
- Actualisation rate

- The time period of the investment
- Energy price
- Cost conversion factor
- Reference energy consumption of the train, without any solution for energy or emission savings (if not available, it is to be required to the applicants to the bid)

Benchmark

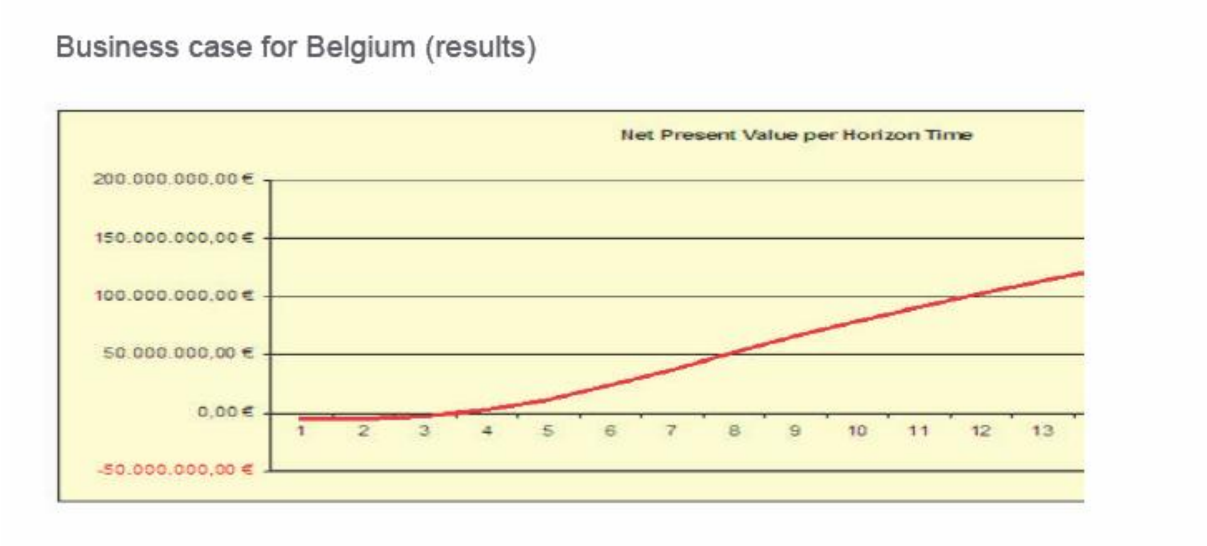
Business case for Belgium (hypothesis)

Onboard equipment	
Number of engines to be equipped	1400
Unitary investment & installation cost per metering equipment (€)	12.000 €
Rythm of equipment (% per year)	15%
Annual maintenance cost per equipment (€)	500 €
Metering equipment lifetime (in years)	8
Metering equipment replacement cost (€)	6.000 €
Unitary driving assistance system cost (€)	2.000 €

Drivers' training & management	
Ratio of the number of drivers / engine	3
Rythm of drivers training (% per year)	20%
Total training cost per driver (€)	2.000 €

Software & Communication	
Initial software investment costs (€)	2.000.000 €
Annual software maintenance & operating costs (€)	500.000 €
Annual communication costs per metering equipment (€)	200 €

Economic parameters	
Potential of energy savings per trained driver (%)	5%
Number of years to achieve potential (training time included)	4
Potential of energy savings through schedule optimization	3%
Number of years to achieve potential	6
Unitary annual consumption per engine (MWH)	2000
Actualisation rate	4,00%
Electricity price per MWH (including transport)	100 €



D7 - Fig. 2-1: Belgium Business case for retrofitting 1.400 engines with energy meters

LCC driven procurement is already implemented at the Danish railways, DSB, for the rolling stock spare parts. LCC are particularly important for DSB, as the majority of the costs relating to the operation and maintenance during the service life of the train is decided by the choices made during the design and construction phase

Reference list

[1] Borghagen L, Brinkhagen L: LCC-Procurement at the Swedish-State-Railways, Proceedings Annual Reliability And Maintainability Symposium, NSYM, pp. 349-358, 1984.

[2] Trümpi A. (1998): Lebenszykluskosten von Schienenfahrzeugen ZEV+DET Glas, Annalen, 9-10/98, p. 648.

[3] Pittius E., B. Laska, R. Beck (2000): Kompromiss zwischen Herstellkosten und Life-Cycle-Kosten bei Bahnfahrzeugen. Elektrische Bahnen, 11-12/2000, p. 453.

[4] Ernst J. (2001): Reducing Life-Cycle Costs by Means of Wide-body Trains on DB's ICE Network. Proceedings of the World Congress of Railway Research WCRR 2001, Cologne, 2001.

[5] http://www.feroforum.com/presentations/08/3_FERO%202008_Girsch.pdf

[6] B. Spiegel, "Energy metering an overview of the complete system", Energy Efficiency day in Tours, France, 23-26 September, 2009

[7] DSB Spare parts LCC-Driven Procurement (http://www.dsb.dk)

INDICATORS	POTENTIALS	
Energy savings potential *	**Electric Traction**	**Diesel Traction**
	20-30 %	≤ 35 %
Pollutants emissions saving potential *:	**Electric Traction**	**Diesel Traction**
CO_2 emission saving potential	depending on energy mix	≤ 35 %
NO_x emission saving potential	depending on energy mix	≤ 35 %
CO emission saving potential	depending on energy mix	≤ 35 %
HC emission saving potential	depending on energy mix	≤ 35 %
Particulate emission saving potential	depending on energy mix	≤ 35 %
Economic potential (on LCC basis)*:		
Implementation Cost (IC)	Medium	
Operational Cost (OC)	Lower	
Maintenance Cost (MC)	Low	
Disposal Cost (DC)	Low	
Implementation time:	**Description**	**years**
Development time	The major hindrance factors are believed to be in the development of a harmonized LCC-driven procurement policy within the different departments. This is the most time consuming echelon.	1-3 years
Administrative time:		
○ Financial	The necessary financial resources cover mainly the human resources needed to implement the strategy and are thus negligible (as the already employed manpower can be utilised).	0 years
○ Technical	Not applicable.	0 years
○ Legal	In case of public ownership time might be needed for incorporating the LCC criteria in procurement processes.	<1 year
○ Management	Decisive factor in this step is the willingness of the top management to introduce LCC driven procurement. The stronger the commitment the less is this time horizon.	<1 year
Construction time Installation time	The needed know-how is available, the time frame needed is quasi zero.	0 years
Total time		1-3 years

* All these potentials are evaluated according to the hypothesis that the market will react to LCC driven procurements implementation offering the best technologies available in the next 1-3 years (the same implementation time estimated for this measure). For example the implementation of the technology has already been evaluated in paragraph 2.1.4. (Braking energy recovering by super-capacitors on board equipment that involve the higher potentials). If these potentials will be higher than the real ones it is not a problem for the implementation of this measure (LCC-Driven Procurement) because the applicants to the bid will be aware to calculate and specify the real one in their offers if these potentials will be evaluated in the commissioning phase and, whenever possible, in the real operation.

2.3. Interdependencies and contradictions between solutions

The matrix in the following page represents the attitude of each solution to be implemented in conjunction with the other solutions considered in this catalogue. At this stage only qualitative judgements have been expressed and the following convention has been used:

- **+** It is profitable to implement the solutions together; in some cases it is possible to achieve higher potentials than the sum of the potentials of each solution.
- **0** The solutions are independent. Implementing the solutions together will not cause any advantages nor disadvantages: the total saving potential is the sum of the single potentials.
- **-** It could be not profitable to implement the solutions together: in some cases the resulting potentials would be lower than the sum of the potentials of each solution.

	Control of comfort functions in parked trains	On-board use of braking energy in diesel-electric stock	Braking energy recovering by super-capacitors on board equipment	Braking energy recovering by super-capacitors in fixed installations	Energy efficient driving by low-tech measures	Multiple units (MUs) vs. loco-hauled trains	Re-engining of diesel stock / Upgrading of engines	Optimisation of traction software	LCC-driven procurement	Database of traction consumption
Control of comfort functions in parked trains		0	0	0	0	+	0	0	0	+
On-board use of braking energy in diesel-electric stock			_	0	_	+	0	+	0	+
Braking energy recovering by super-capacitors on board equipment				_	_ [2]	+	0	+	0	+
Braking energy recovering by super-capacitors in fixed installations					_ [3]	+	0	0	0	+
Energy efficient driving by low-tech measures						+	0	+	0	+
Multiple units (MUs) vs. loco-hauled trains							0	0	0	+
Re-engining of diesel stock / Upgrading of engines								0	0	+
Optimisation of traction software									0	+
LCC-driven procurement										+
Database of traction consumption										

[2] This assessment depends on operation and characteristics of the trains. This aspect should influence the strategy adopted for the driving style in relation also to the power of the train. If a braking energy recovering storage system exists and the train has the needed power available, a Coasting strategy [6],[7] could be adopted to save energy and this assessment could be changed in a +, but if we adopt all the other strategies (see *Description* in paragraph 2.2.1) we reduce the number of braking phases and speed and consequently the energy stored on board (i.e. what it is saved up by energy efficient driving reduces the effectiveness of the braking energy recovering if the capacity of the storage systems it is not overfilled in any case (e.g. due to a low storage capacity).