Evaluation of traction energy savings in railway sector

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Abstract
Methodologies and steps needed for improved energy performance in building such as performance contracting is confirmed by many successful cases. True, buildings are responsible for important part of overall energy consumption. However, energy consumption in transport rises dramatically and in many countries causes equal or even bigger environmental impact than buildings energy consumption. Rail transport is environmentally friendly mode of transport. Yet in the past years railways has been slower in acknowledging its own needs for efficiency improvements and has lost some of its head start. More intensive use of railways instead of road transport could drastically reduce the environmental impact of the transport sector. For this change improved and cheaper railway services are required. Cheaper railway service could be assured also with lower energy consumption. Investments in railway supply grid, traction technology and in staff education demand financial means. But railways often suffer from a lack of financial means. Performance contracting could be a way to implement those needed efficiency measures. Defining a baseline, critical for success, is even more difficult in railways than in buildings. The paper discusses the methodology of evaluation of energy efficiency improvements on railways: methodology, including defining key factors and their influence, data-collection and technology required for this based on a case study from Slovenian Railways.

Introduction
Transport was singled out already at the Rio Earth Summit in 1992 as a key area in order to achieve sustainable development. Nevertheless, the sector today accounts for approximately 30 % of global CO_2 emissions making it the second largest contributor after the electricity and heat supply sector. One of the main reasons behind this poor performance is the enormous increase in transport demand - in both passenger and freight services. Yet, for the enlarged European Union, the modal share of rail freight declined from 19.5 % in 1995 to 16.4 % in 2004 [1].

Rail transport is still considered to be the most environmentally friendly mode of transport. Freight transportation produces only around 1/5 of GHG of what an average lorry is responsible for. In long distance person transport the figure is 1/3 to ¼, in local and short distance transport it is half of what a car produces [2]. Also, rail transport based on electric traction is already adapted for the use of renewable energy sources. A more efficient rail sector could contribute to alleviate problems of congestion and meet safety as well as environmental concerns. The revitalisation of railways as an alternative transport mode to more polluting ones is deemed fundamental for the future of Transport in Europe [3]. One trigger to make railways more attractive is lower railway prices. The EU introduced the principle of separation between infrastructure (infrastructure managers) and operations (railway undertakings). A major reason for the choice of separation in Europe is the expected improvement of cost transparency and predictability. One of important costs in structure of overall costs is also energy costs ranging from 10 to 15 %.

Railway infrastructure managers care for energy supply. They are obliged to split costs of electricity between railways undertakings in a transparent way; where possible on the basis of metered data. If train operators have to pay for the energy actually consumed rather than a system average, they have an incentive to reduce energy consumption. Furthermore, measured data of energy consumption and other parameters (e.g. position, speed), first time available in that huge volume, can be extremely valuable for energy efficiency actions of railway undertakings as well as infrastructure managers.

Parallel processes to the unbundling are deregulation and privatisation of railway undertakings. Deregulation in a first step leads to new entrants to the market and to increased cross-border traffic. This has increased the pressure throughout Europe on railway undertakings to be cost-effective and competitive within their networks to other railway undertakings and also towards road transport. Hence became – with view to increased fuel and electricity costs – energy efficiency a key challenge for today's railway undertakings for reasons of cost effectiveness but also environmental competition.

Other interested parties are energy companies. Railways are big consumers of electricity and diesel fuels. Energy companies will have to offer additional services to attract them and also to fulfil The Energy End-use Efficiency and Energy Services Directive. Only railways use electricity for traction purposes and that makes them unique comparing to other consumers. Special knowledge is necessary to offer services, which would improve energy efficiency. In addition, existing protocols and guidelines for measurement of energy saving intensely used for buildings and industry, are not covering transport sector.

To facilitate energy services in railway sector methodology for measurement of energy saving is of crucial importance. Essential step of energy saving measurements is setting a baseline. Energy consumption for railway traction depends on track, train and engine properties, weather, on driving strategy and train dispatchers' behaviour. In this paper a methodology for setting the baseline and the choice of relevant independent variables is shown.

Opportunity for Energy Service Companies

With recognized need for better energy efficiency also energy service market for railway companies is developing. Energy service companies (ESCO), which are still focusing mostly on industry and building sector, are entering energy railway market, but still limited to buildings [4]. With involvement of railway specialists ESCOs could provide measures and investments also on the traction and railway infrastructure. They could provide knowledge for improved energy efficiency on existing traction units, existing infrastructure and more efficient new units and infrastructure parts.

Railway undertakings vary in fleet largeness, in types of vehicle they use and routes they drive on. In order to foster implementation of energy services in railways ESCOs need tool for transparent evaluation of potential savings in specific railway undertaking and/or specific network. Since many ESCOs already have experiences from other sectors with procedures, it would lower transaction costs and speed up implementation of energy efficiency actions if those companies could use the same, already proven tools for monitoring and evaluation of the railway energy actions. The International Performance Measurement and Verification Protocol (IPMVP) as a General Protocol and ASHRAE 14 as Technical Guidelines are appropriate.

Information system for railway energy management

Because of the challenges outlined above, but also for billing reasons, Slovenian Railways – both the infrastructure manager and railways undertaking – have started to invest in an information system for energy management as a response. This system is used as a basis for baseline development in the present paper.

The system implemented in Slovenian Railways collects all data which are necessary to perform billing of the energy used on engines. The supplier knows not only how much energy and when it was used on the specific engine, but also where it was used. This is important in the case when engine passes more energy price zones and/or more energy suppliers.

SETTING

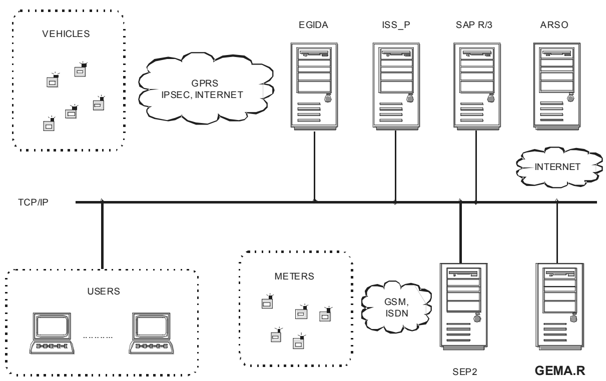

Fig.1. Communication block diagram.

The information system for energy management, Genera Lynx's GEMA.R enables survey, analysis and forecasting of data that is relevant for energy consumption of railways traction and infrastructure units. It is a web-based software solution. Users access it through enterprise intranet or internet, mobile GSM and PDA devices. It uses database of arbitrary type and OLAP technology for data mining. In conjunction with GSMBOX-R a data logging and communication device produced by Genera Lynx, processes all data necessary for efficient measurement of energy savings on railways. Besides energy usage on the engines GEMA.R collects read outs of substations and railways buildings meters from automatic meters reading. GEMA.R exchanges information also with traffic management system (ISSŽP) to get data of train properties (mass, length, type of the train and number of engine) and timetables. To perform billing and cost analyses with ERP system relevant data are exchanged. Furthermore, for energy efficiency analyses and consumption forecasting weather data are imported from Slovenian environmental agency (ARSO) (Fig. 1).

ON BOARD DEVICE

The GSMBOX-R holds energy meter and GPRS communication device and is mounted in the cabin of the engine. The GPS receiver is mounted on the roof of the engine. A communication device reads meter and GPS device in one minute resolution and sends data files into the central server.

Savings definition

RELEVANT INDEPENDENT VARIABLES

According to ASHRAE 14 [5] Preparation of Monitoring &Verification plan is first step to energy saving measurement. Because of the reasons which go beyond the scope of the paper, authors propose use of Whole Building Performance Approach (the interested reader can find more on www.railway-energy.eu). Next step is to design the baseline model, which includes all relevant independent variables. ASHRAE 14 exposes linear regression as common technique to correlate energy use and independent variables. In this paragraph independent variables which could be used in linear regression model are discussed.

On the one hand, a small number of independent variables make the process of measurement easier to implement and to understand. On the other side all variables which are the influencing functions of the energy-using system should be considered in any savings calculation.

Geographical and Technology Dependant Variables

- Length, average grade and curve resistance of the track,
- Length L and mass m of the train,
- Comfort functions,
- On board energy conversion efficiency,
- Train type and composition (passenger, cargo, sequence of coaches).

Operations Dependant Variables

In addition to production and technology, driving pattern and traffic management have significant impact on energy usage and can reach more than 10 % [7, 8, 9]. Drivers could reduce energy consumption mostly with smarter coasting [10, 11], traffic dispatchers with decreased number of stops. In addition to this for railway use parameter coasting ratio is significant. Those variables can be calculated on the basis of velocity profile.

- Average velocity v_{avg} is defined as

$$v_{avg} = \frac{1}{T}\int_0^T v dt$$

- Cumulative kinetic energy changes

$$\Delta_{Ecum} = v_{final}^2 - v_{initial}^2$$

  - where v_{final} and $v_{initial}$ are velocities in successive acceleration/deceleration manoeuvres. It quantifies the changes of kinetic energy due to acceleration and deceleration.

- Coasting ratio

$$\tau = \frac{\sum T_{coast}}{T}$$

  - where T_{coast} is a duration of coasting period and T total trip time. It quantifies the proportion of time, comparing to the total trip time, when driver drives without powering, using accumulated kinetic energy instead.

- Average coasting time

$$\overline{T_{coast}} = \frac{\sum T_{coast}}{N}$$

  - where T_{coast} is duration of coasting period and N number of coasting periods per trip. Shorter coasting periods could occur also during braking and are not necessarily a sign of energy efficient driving. Longer average coasting time shows a positive attitude of engine driver to energy efficient driving.

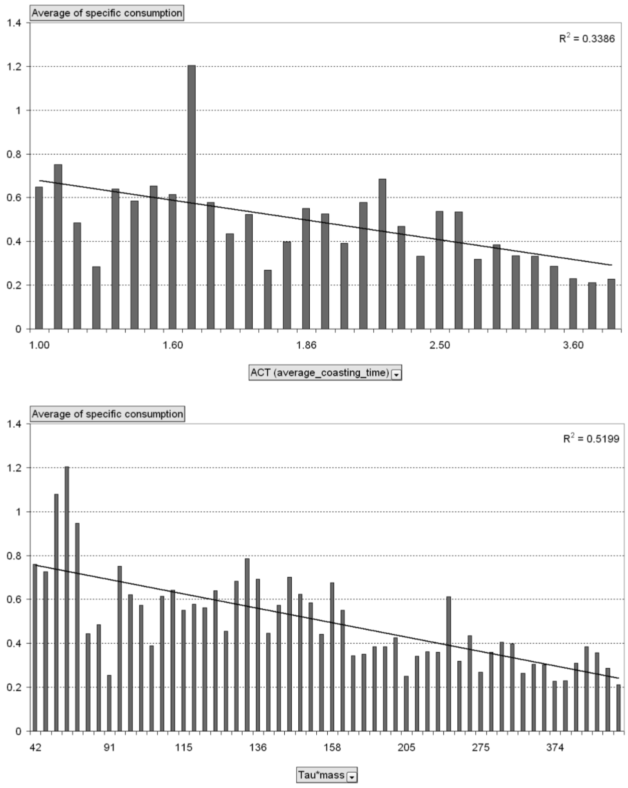

Fig. 2. Specific consumption of train as function of average coasting time and as a function of product of coasting ratio and train mass.

Those are main variables which influence energy use. On the Figure 2 it is shown the test of two operation dependant variables with the set of 56 trains. Since there are many variables influencing on energy consumption, high variances are visible for both tested variables. However, correlation is high enough to include both variables into the model. All variables are tested in that way and influencing included into the baseline model.

BASELINE MODEL

One method to define base energy use is to create on baseline for the whole network, considering all geographical variables. Authors prefer another, simpler way: to define base energy use for each section of the railway network included into the project. Any section should not be longer than the shortest trip which could occur; so each trip consists of at least one section. For each section base use with regard to baseline independent variables should be defined. Recommended baseline period is one year, mainly because weather influence in many ways, not only through temperature which is relatively easy to include into the baseline (but also rain, snow, frost). In that way influence of those phenomena is mitigated. Baseline energy use for each section is defined as:

$$E_i = a_{i0} + a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + a_{i4}x_4 ...$$

where ai are the coefficients of the independent variables, specific for each section, and xi are the independent variables. The coefficients are calculated on the basis of metered data in the baseline period with multiple regression analyses or another appropriate method.

Concretizing the equation above, for specific section of Slovenian railways the equation looks like

$$E = a_1 L + a_2 m + a_3 v_{avg} + a_4 v_{avg}^2 + a_5 \Delta_{Ecum} + a_6 \lambda + a_7 \overline{T}_{coast} + a_8 \lambda m$$

For particular trip energy use is calculated, considering the variables, compared to metered energy use, adjusted if necessary and energy saving calculated. Energy savings of the project are sum of particular trip savings.

Conclusions

Electric meters on board of the engines and belonging information communication technology will be a necessity for all railway operators which will perform international traffic in European tracks in few years. On that basis traction energy billing will be performed. To fulfil that need Slovenian railways set up an information energy management system. In addition to collection data for billing purposes it represents good basis for measurement of energy savings.

In order to do that transparent and easy to implement methodology is necessary. Paper discusses methodology of setting of baseline and propose list of key independent variables, which impact significantly on energy use. In the paper proposed methodology is a basement for defining energy savings on the railway engines. Those savings could be result of modification of technology or of the staff training, engine drivers and traffic operators.

Each train trip is metered and all variables registered (technology impact, impact of engine drivers and traffic dispatchers). That is why ESCOs, which will perform certain actions (such as change of technology, training) will be able to give guarantees. Guarantees can be on the level of savings or cap for consumption for certain train trip, certain engine, engine drivers, for the whole traffic on the certain section or even for the whole network. Based on a baseline that implies certain conditions or summer/winter differentiated conditions.

The goal of this paper at this stage is not to already look into all the economics and tendering etc. for ESCO projects, but at the applicability of a known and tested model (EPC) and methodology (ASHRAE 14 and IPMVP) to a new sector by looking at one of the key issues for any such project, the development of the baseline. Authors are aware however that the savings potential are sufficient to further follow the idea to railways EPC projects.

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