Examining the load peaks in high-speed railway transport

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1 Abstract

Due to the increasing costs, transport demand and the climate change, the importance of energy efficiency is increasing. The highest proportion of energy consumed in the railway is the so called *traction energy*. This energy is required for the train run between two stops. Railway traffic is managed by timetables. Consequently, as long as the punctuality is assured the timetable design plays a decisive role on the energy consumption and its allocation over time.

In railway transport, the energy consumption will be for periods of 15 minutes by energy supplier measured. Load peaks may occur in these periods due to the changes in train numbers or other factors. These peaks cause high costs for the railway operators because of the price policy of energy suppliers.

Energy consumption peaks are partially inevitable due to the timetable design. The most significant factor is naturally the number of trains in a period of 15 minutes, which is based on the transport demand and cannot be affected without changing the already existing and valid timetable. On the contrary, the train speed and acceleration, which are also significant factors especially on high-speed railway transport, can be adjusted so that the load peaks due to the train runs can be avoided. Hence, this study focuses on the influence of these factors on the energy consumption and gives recommendations about the speed profiles. The objective is to verify the significance of factor train speed and acceleration.

Keywords: traction energy, optimization, railway operation

2 Introduction

The importance of the energy efficiency is becoming more significant. Energy efficiency in railway traffic can be measured by the energy consumption per train unit km. To achieve higher energy efficiency less energy per train unit per km should be consumed.

Energy efficiency is not the only factor that determines if a rail transport company operates efficiently. Analysis of the measured data from *Deutsche Bahn Fernverkehr AG* (german high-speed train operating company, abbr. *DB Fernverkehr AG*) shows that the energy consumption in certain time periods is higher than other time periods. Figure 1 shows that i.a. between 17:30 and 17:45 the highest energy consumption occurs. This situation has many consequences. Firstly, energy pricing is higher at peaks which results in higher costs for train operating companies. Since DB Fernverkehr AG uses exclusively green energy the storage of the energy is a problem. In this respect the objective of this study is to examine the causes of the energy peaks and make recommendations on how to reduce energy peaks for DB Fernverkehr AG.

Energy providers charge for the peak hours higher, because of the increase in supply price. This can have a significant impact on traction costs of a train operating company. Quick energy, generated by peaking power plants (for example natural gas fueled or pumped storage power plants) has its higher costs.

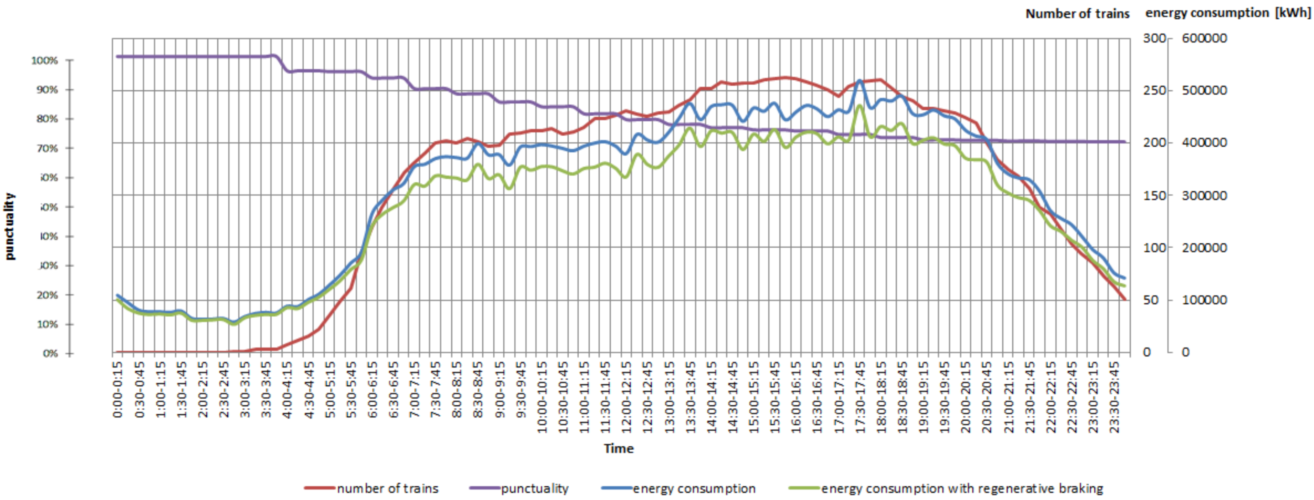

Figure 1: Energy consumption peaks on 28.05.2014

Railway traffic can be regarded as a production process. In this respect, railway operation research defines three phases of a train run: network planning, timetable planning and operation (see Figure 2). Although the traction energy will only be consumed in phase train operation, the amount of the consumed energy also depends on the decisions in other phases. For example the output of network planning are train lines, destinations and stops. Depending on this information and other factors (e.g. other train operating companies or the capacity of the train routes) a timetable will be generated. Then again the timetable defines when the trains will run with which maximum speed and allowances for an energy efficient driving-style. As a result, timetable might be a reason why these peak hours occur.

Figure 2: Phases of a train run

Terminology

A travel time between two stop points consists of pure running time and allowances. Pure running time is defined in [1] as the time in which a train is taking advantage of the traction unit, observes the speed limits and adopted dynamic driving conditions (inertia coefficient, friction coefficient, braking conditions, air resistance, etc.) can be performed. For non-uniform traffic demand, the waiting for delayed connections but also for the unexpected effects like weather or temporary speed restrictions must be taken into account, so that minor delays can be reduced. For these reasons, allowances should be planned.

Energy consumption in this paper signifies only the tractive energy consumption which is required for the train run between two stops. Other energy consumers in a train like air-conditioning or lightening are not considered.

Mentioned high-speed section in this paper includes only train speeds over 250 km/h.

Deutsche Bahn Fernverkehr

DB Fernverkehr AG is a rail transport company which operates regular national and international long-distance passanger trains. According to [4] in Germany over 700 daily high-speed connections are frequented. In addition to that around 250 international connections to 80 European cities are provided. Thus daily around 340000 passengers travel with InterCityExpress (ICE), InterCity (IC), and EuroCity (EC) trains of *DB Fernverkehr AG*.

Energy efficiency belongs to the guiding principle of *DB Fernverkehr AG* next to the safety and punctuality. The results of this paper are a product of research cooperation between *DB Fernverkehr AG* and *Technische Universität Darmstadt* about energy efficiency.

Influence factors on energy consumption

According to [2] the most important influence factors on energy consumption are temperature, vehicles, punctuality and mode of operation which can be altered by different driving strategies.

The results of a sensitivity analysis in [3] show that also train mass and top speed are significant influence factors.

Figure 1 shows the results of the complete train runs of *DB Fernverkehr AG* in one day. Due to the fact that the number of trains and punctuality around peak times are not varying much the hypothesis is that the reasons of the energy peaks are mode of operation and top speed.

Trains use most of their energy to compensate resistance which are caused by different conditions. These are structural like tunnel or curve resistances, but mainly speed related resistances. As can be seen in function of Keßler/Junker (1) the air resistances are proportional to the square of the velocity. With higher speeds resistances are higher and as a consequence the energy consumption is also much higher. In this respect, speed has a major impact on energy consumption.

$$w_l = a_0 + a_1 \cdot V + a_2 \cdot V^2 \quad (1)$$

a_0 describes the roll resistance

$a_1 \cdot V$ describes the pulse resistance moving air masses

$a_2 \cdot V^2$ describes the air resistance

Definition of study area for analysis of timetable

In this paper, only new high-speed lines will be considered: Hannover-Würzburg, Frankfurt-Köln, Mannheim-Stuttgart, Nürnberg-Ingolstadt, Hannover-Berlin and Karlsruhe-Basel. The reason for that is the maximum permissible speed. Only these lines contain high-speed sections, where trains achieve speeds over 250 km/h.

The study will be conducted for the peak days 28.05.2014 and 25.07.2014. These days were with the highest energy consumption. There are many peaks on these days that occur regularly. In this paper only 25.07.2014 will be considered. The methodology and results do not vary.

For further research only the peak between 14:00-15:00 will be studied. This peak is selected due to the constant number of trains. In order to get correct results it is necessary to extend the period of investigation at least one hour, otherwise trains that are already driving could not be included. In this respect the period of investigation is between 13:00-15:00.

Only ICE trains can achieve high-speed sections. Insofar only this class of train will be considered.

3 Methodology

Principles

At first, the energy consumption dependent on target speed was calculated in order to prove the hypothesis that acceleration in the high-speed section is high energy consuming. The calculations are computed for an ICE3 train on a slopeless line and are based on the basic formulas of train dynamics which may be found in [3].

Speed section [km/h]	Energy consumption [kWh]	Energy consumption per speed difference [kWh/km/h]
0-250	604,94	2,42
0-300	869,95	2,90
250-300	265,02	5,30

Table 1: Energy consumption dependent on target speed

Table 1 shows that energy consumption for 1 km/h acceleration in the high-speed section is more than the double energy consumption for 1 km/h acceleration in lower speeds. Although the high-speed section contains only a small span of speed it has relatively higher importance on energy consumption.

Analysis of Timetable

For the purpose of time allocation of ICE trains in the high-speed section the timetable and the actual train runs of *DB Fernverkehr AG* was analyzed. The data contains information about departure, arrival and thoroughfare times with six seconds accuracy. Times are differentiated between timetable and actual times. Hence, it is also possible to access delay times. Furthermore, trains may be identified with train and line number.

First, the required time to accelerate in the high-speed section is determined for each operation control post (train station) on new high-speed lines by observations or if available by measured data. For example for the line Nürnberg-Ingolstadt in direction to Ingolstadt from operation control post Nürnberg Reichswald 5 minutes are required to accelerate in the high-speed section. This time was added to departure or thoroughfare times in order to acquire the actual times when trains arrive the high-speed section. By doing so all ICE trains on these lines are allocated to time intervals of 15 minutes to determine the number of trains which are accelerating in the high-speed section. These train numbers are the basis of the comparison. If the numbers are higher in peak intervals, it indicates that high energy consumptions are resulted from these trains.

Calculation of energy consumption

Total tractive energy consumption consists of three driving regimes:

$$e_{total,i} = e_{accelaration,j} + e_{crusing,k} - e_{braking,k,l} \tag{2}$$

where i is the driving style, j is the speed, k is the target speed and l is the braking mode. The difference to the running time calculation is the negative sign of the braking regime. This sign describes the regenerative braking energy. The energy consumption is calculated in kWh. Energy-saving driving styles may contain also the driving regime *coasting*. Due to the very low friction between wheel and rail it is possible to coast long distances without traction power. The coasting distance is dependent on many conditions such as slopes, current speed, weight and weather. In this driving regime, there will be no energy consumed since there is no traction power required.

Input

The basis of this study is the timetable of *DB Fernverkehr AG.* The timetable contains information about departure, arrival and thoroughfare times with six seconds accuracy. Trains may be identified with train and line number. Timetable was localized in order to access only the required information on the lines of study area. As input the number of trains that are accelerating in the high-speed section is conducted.

Input for the energy consumption calculations are train and infrastructure properties.

4 Results

With the aid of the Microsoft Excel program, the timetable data was analyzed to determine the train numbers in time intervals. The results are given separately for each peak days.

28.05.2014

Figure 3 shows the results for peak day 28.05.2014 in peak hour 17:00-18:00 with intervals of 15 minutes. The blue bar shows the actual number of trains that are driving in the high-speed section and the red bar shows the number of trains according to the timetable that should be driving in the high-speed section.

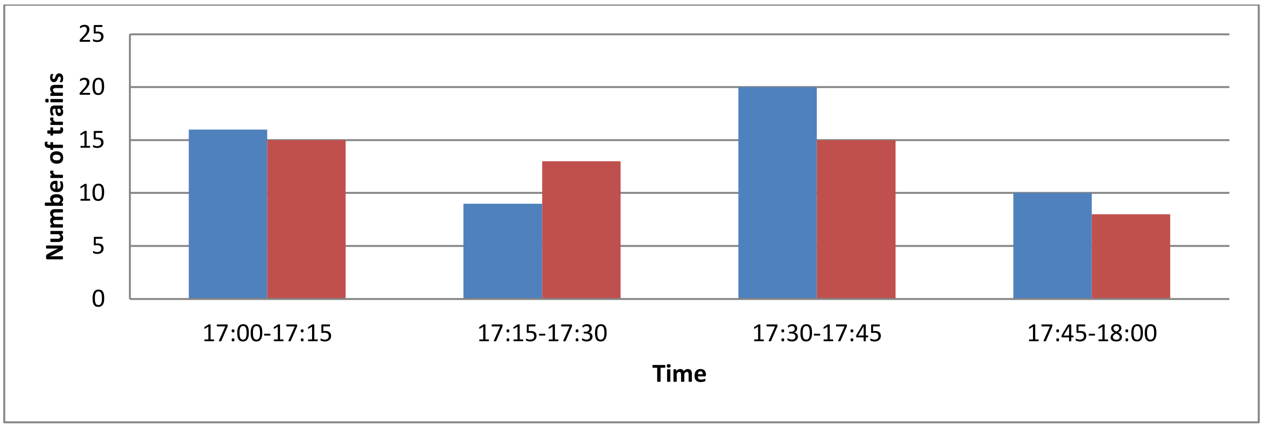

Figure 3: Results of 28.05.2014

The data of the energy consumption analysis of *DB Fernverkehr AG (see Table 2)* shows that the total energy consumption between 17:30-17:45 is highest. Even though in next time interval only one more train is driving in system there is a difference of 59869.49 kWh. This difference results from the high number of trains that are driving in the high-speed section. As seen in figure 3 the actual number of trains between 17:30-17:45 is the double of the number between 17:45-18:00.

Time	Total number of trains	Energy consumption [kWh]	Regenerative energy [kWh]	Total energy consumption [kWh]
17:00-17:15	245	463306.559	51539.067	411767.492
17:15-17:30	254	461033.644	55052.318	405981.326
17:30-17:45	258	519533.067	47842.416	471690.651
17:45-18:00	259	467258.59	55437.437	411821.153

Table 2: Energy consumption on 28.05.2014

25.07.2014

The results for peak day 25.07.2014 can be seen in figure 4 and table 3. These results confirm the results of peak day 28.05.2014. Again the time interval with the highest energy consumption is the time interval with the highest number of trains that are driving in the high-speed section.

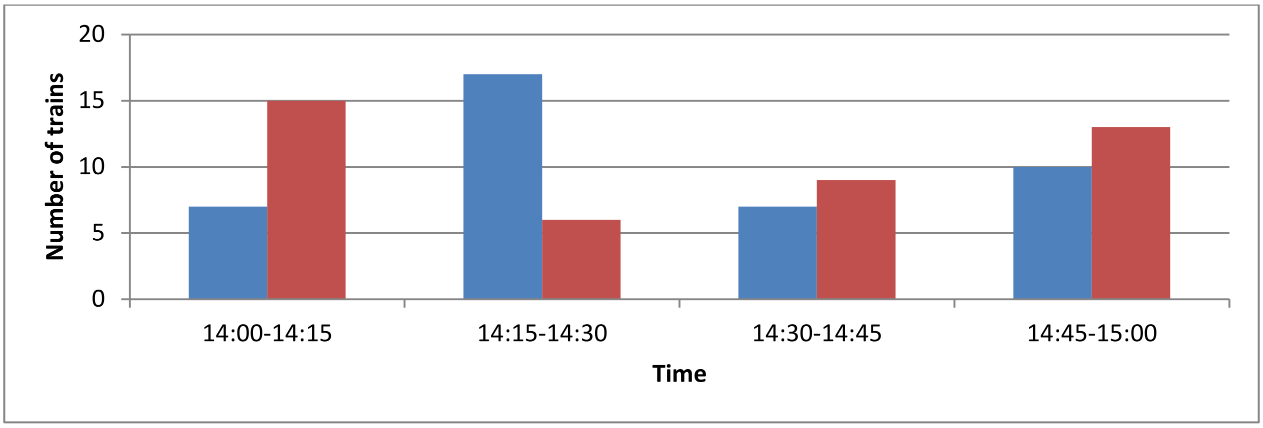

Figure 4: Results of 25.07.2014

Time	Total number of trains	Energy consumption [kWh]	Regenerative energy [kWh]	Total energy consumption [kWh]
14:00-14:15	251	464805.749	59468.356	405337.393
14:15-14:30	254	500683.71	58122.596	442561.114
14:30-14:45	251	453553.689	54255.279	399298.41
14:45-15:00	251	455390.004	54125.831	401264.173

Table 3: Energy consumption on 25.07.2014

Relation to Energy Consumption

Figure 5 shows the results of calculations for the energy consumption. The red bar shows the energy consumption due to the trains that are driving in the high-speed section. It is clear that maximum speed, a property of timetable, has a high impact on energy consumption and therefore may cause as appropriate energy consumption peaks.

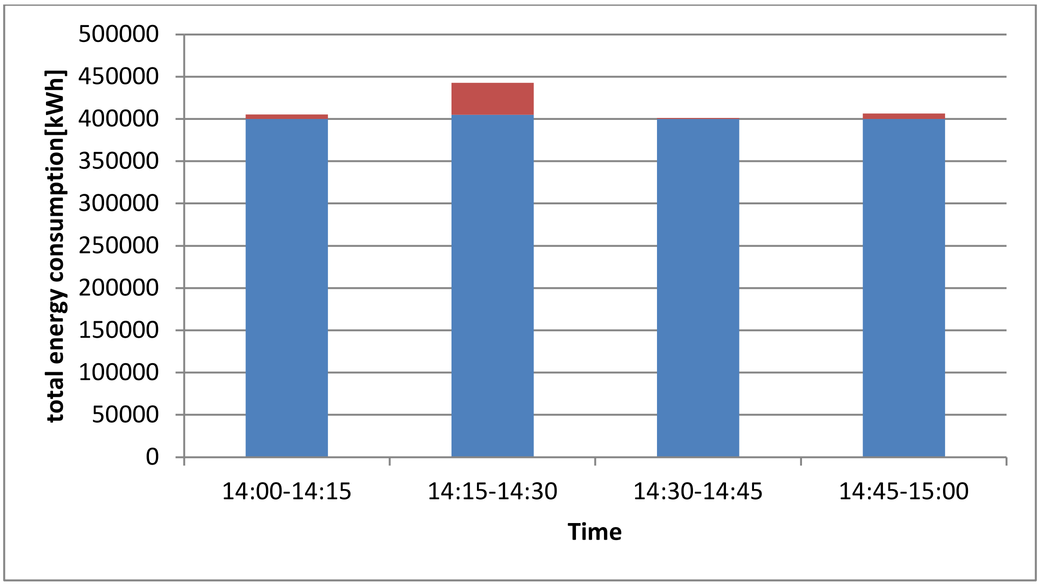

Figure 5: Classification of the energy consumption on 25.07.2014

5 ACKNOWLEDGMENTS

To find the reasons of the peaks on energy consumption theoretical and practical studies were applied. Theoretical calculations of energy consumption show that in high-speed sections more energy is required to accelerate.

In order to verify the acknowledgments from theoretical calculations an analysis of timetable from *DB Fernverkehr AG* was conducted. Study area was restricted to new high-speed lines and ICE trains. The results show that number of trains that accelerate in the high-speed section has an influence on energy consumption that leads to energy peaks.

In summary, it can be stated that among the numerous influence factors on energy consumption mode of operation and top speed have a high impact. In order to increase energy efficiency and reduce costs a good timetable design is necessary. It is also conceivable to develop and integrate an energy demand management to driver advisory systems in order to prevent predictable peak demand.

For further research, it is recommended to perform a sensitivity analysis of top speed in order to determine the potential of reducing the peaks. In the sensitivity analysis also running times should be considered. Furthermore, it is recommended to investigate the effects of changes in departure times and timetable. For this purpose a timetable simulation tool may be used.

List of Figures

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