Chapter 2
Rail Operations and Energy Management

Martin Lehnert and Stefano Ricci

2.1 Motivation and Introduction

A global important ecological and economical aspect is the reduction of energy consumption. This aim has to be fulfilled also in the transport sector. Although the rail transportation is a very ecological transport system itself, it is faced with request to save energy and costs, too. Measures have to be taken to stay competitive with developments in other transport sectors, like road traffic.

Modern traffic management systems can help to decrease energy consumption. Rail operation needs command and control like any complex transport system, anyway. Thus, a modern rail operation and traffic management system can reflect the energy saving and other customer needs beside the common tasks of securing an unobstructed operation corresponding to timetables and handling disruptions.

This chapter will reflect different aspects in that topic. First, a systematic approach on different influence levels of rail traffic management will be outlined. A systematisation of the different tasks in the management process should help students, researchers, professionals and any newcomers to the discipline to get an introduction and a common understanding of the area of rail traffic management. Therefore, a traffic management cycle will be developed and presented while complex mathematical models will be avoided.

Energy-saving methods will be introduced in the second section. A variety of measures will be pointed out which effect by influencing driving behaviour with different strategies, by effective usage of the power train and its zones of best aggregate efficiency and by design issues of the vehicles and fixed infrastructure

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M. Lehnert (✉)
Technische Universität Dresden, Dresden, Germany
e-mail: martin.lehnert@tu-dresden.de

S. Ricci (✉)
Sapienza Università di Roma, Rome, Italy
e-mail: stefano.ricci@uniroma1.it

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installations. Furthermore, a special attention will be given to apply these measures to Mass Rapid Transit (MRT).

One of these aspects to influence the driving behaviour will be focused in the following section. Driver Advisory Systems (DAS) are an efficient measure and can be integrated in the systematic of rail traffic management from the beginning as well. They can support drivers to ensure energy-efficient driving on the one hand by having all freedom to react to and to consider deviation from usual and planned run on the other hand. The systems will be motivated and systemized. Some examples from daily operation will complete the section.

2.2 Influence Levels for Traffic Management in Rail

(By Martin Lehnert)

2.2.1 Types of Conflicts on Different Influence Levels

Based on the scope of traffic management, which is to influence and optimise the train operation, a classification in different influence levels of traffic management offered itself. These levels (Fig. 2.1) refer to different size of focused areas and different number and kind of involved vehicles. For each level it is attempted to characterise it with a set of conflict types:

- Level 1: Optimisation of one train running between two consecutive stations. This level is located at the base of the pyramid in Fig. 2.1. It affects the smallest area and refers to conflicts regarding one train running between only two consecutive stations. Conflicts regarding timetable (delays) occur on this level as well as on the level above.

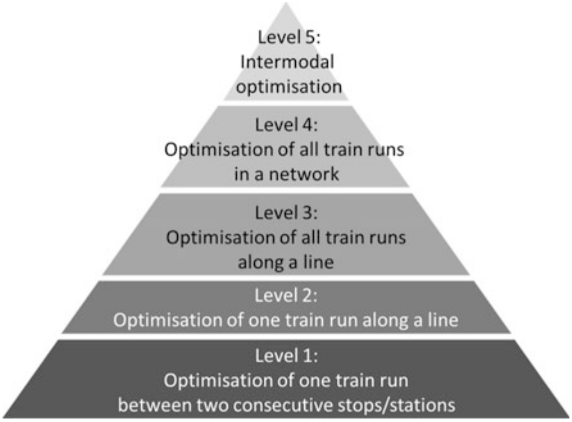


Fig. 2.1 Influence levels on traffic management

- Level 2: Optimisation of one train on a line.
  This level is consecutive to the first level and focusses similarly one train but a wider area, namely a whole line. It can refer to the following types of conflicts:
  - Allocation set conflicts (resources, staff and/or vehicles need to be at a certain position at a certain time but they are not available there and then),
  - Track occupation conflict in the terms of avoiding red signal stops and
  - Conflicts regarding timetable (delay, energy consumption, etc.)

Although in the context of this level the train running behind schedule has no effect on other services, it could cause increased energy consumption or issues with staffing levels.

- Level 3: Optimisation of all trains running along a line.
  This level includes more than one train in the management and control process, so it refers to conflicts involved with multiple trains but still running along a line. The kinds of conflicts on this level are in general the same as on the following level, but with smaller consequences and influenced area. In fact, the area is limited to the single line and the train running along this line only. Such scenario can be found in local public transport often. The conflicts can be summarised together with the following level.
- Level 4: Optimisation of all trains running in a network.
  On level 4, the management focuses on the whole railway network with many trains running within. The conflicts on this level are between several trains in the network as there are:
  - Track occupation conflicts (train spacing, headway and train order in junctions and network bottlenecks as well as on main track)
  - Connection conflicts for both customer groups (passenger and freight) as well as for staff and rolling stock.
- Level 5: Intermodal optimisation.
  This top level of the pyramid takes different transportation systems into account. This is obvious in public passenger transport in fact of the intermodal transport chains. The level refers to all intermodal conflicts in the meaning of at least two transport modes involved, e.g.
  - Intermodal occupation conflicts (e.g. conflict between tram and car at crossings, or between train and car at level crossings)
  - Intermodal connection conflicts (e.g. connections between tram and bus, or between regional train and regional public transport).

While there are commercial solutions for problems on the levels 1 to 3, optimisations at network level (level 4) are still in prototype and for more complex areas under research. In the past 5 years, the problems on level 5 came more and more into focus of research as providers strive for connectivity across all modes of public transport to encourage greater passenger numbers in the future. A key problem with public transport can be a lack of viable connections when a direct journey is not available and so greater connectivity between transport modes could solve this major problem.

The solutions of mentioned conflicts lay on the mentioned level to reach effective railway traffic. But it is important when surveying traffic management to consider the entire picture and not concentrate on only one or two types of conflict.

2.2.2 *Traffic Management Cycle*

Regarding the definition of management and traffic management (EN ISO 2015; ON-TIME 2012) the transportation process has to be directed, controlled and supervised continuously. This means collecting the relevant traffic data, analysing and comparing it with the requested state, predicting the development in the near future, detecting and solving conflicts and bringing the solution back to the transportation process by influencing the traffic flow in different kinds. Thus, traffic management can be described as a cycle or control loop with various actions (Fig. 2.2).

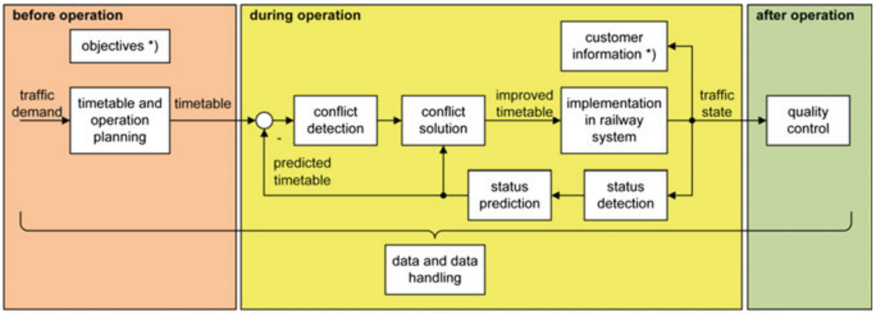
In all actions the infrastructure manager (IM) and the railway undertakings (RU) are involved in some kind. Additional involvement of the customer can be found during the definition of objectives and during the customer information action.

Regarding to the time the different actions can be grouped in three steps (see Fig. 2.2):

- Actions before operation;
- Actions during operation;
- Actions after operation.

There are two actions in the traffic management cycle, which take place before the operation starts. These are:

- Definition of Objectives;
- Timetable and operation planning.



*) additional to infrastructure manager (IM) and railway undertaking (RU) the customer (passenger, freight) is involved here

Fig. 2.2 Traffic management cycle (adapted from Jaekel 2013)

Actions in the traffic management cycle that take place during operation include:

- Status detection;
- Status prediction;
- Conflict detection;
- Conflict solution;
- Implementation of the solution in the railway system;
- Customer information;
- Data and data handling.

One more action in the traffic management cycle occurs after the operation completion:

- Quality control.

All actions will be described in the following.

2.2.2.1 Objectives

Objectives need to be set to make a process controllable in a desired direction. The most essential and a process immanent objective is to perform the transport task that has been set. Further objectives include safety, optimal use of infrastructure, punctuality and to minimise resource use (vehicles, staff, energy use, etc.). The order of these objectives depends on the role of the participant in the process. For infrastructure managers an optimal infrastructure usage might have the highest priority. From the view of the customer, here e.g. in the meaning of the passenger, the punctuality and safety might be most important. For the railway undertaking, it is of commercial importance to minimise resource usage and costs while focussing on customer needs.

2.2.2.2 Timetable and Operation Planning

The timetable and operation planning task requires a process of considering supply and demand. When designing a timetable, many variables must be taken into account such as scheduling of resources like staff, vehicles and operating supplies and consumables.

The timetable process is subdivided in several chronological and detailed steps from the demand requests of the railway undertakings to the general routes allocation and the fine planning with the precise train configuration at a certain day. Passenger changes at stations to meet either other rail services or intermodal connections must also be considered when designing an effective timetable.

Last but not least, all decisions in timetable planning result in economic impacts to the participants.

2.2.2.3 Status Detection

In the second step, all actions relevant during operation are grouped. This is the core of traffic management cycle. Starting in the cycle with the railway system as the controlled system in the cycle the first action in focus is the status detection—that means the monitoring and constant measurement of current railway operation. These measures include a huge number of physical and operational measured variables and indicators, as there are, for example time, position, speed, track occupation, train integrity or number of passengers, etc. as well as values and interpretations derived from that measurement like the relation to timetable.

The data measurement bases on different technical and physical principles, like optical, mechanical, inductive or magnetic mechanism. Post-measurement, transmission of data and its subsequent processing are necessary, considering the accuracy and time resolution of any data. (Albrecht et al. 2013b)

2.2.2.4 Status Prediction

From the data previously gathered, a status prediction must be made which forecasts the state evolution of both traffic (e.g. train positions and speeds) and infrastructure (e.g. route settings, signal aspects, switch positions) within a certain time period ahead named prediction horizon. This can be done in a variety of methods or using a combination of them such as:

- Linear propagation, e.g. for delays: The current delay will be forecasted with the same value for all the following stations. Further influences are not taken into account.
- Predictions, e.g. of traffic state, which takes the behaviour of surrounding trains and current traffic flow as well as further constraints (crew, rolling stock, connection constraints) into account. This is very complex and can be solved by simulation based prediction approaches.
- Stochastically prediction: The knowledge of a huge number of historical realisations of this dedicated train run and if available different influencing factors can be combined and build the fundament for mathematical, stochastically approaches.

On example of effects that can be achieved is shown in (Binder and Albrecht 2012) by predicting the dwell time in subway stations in Hamburg and the use of this information to optimise the operation.

One additional approach of the past years can be summarised with the keyword “big data”. Within that approach a huge amount of data from various sources will be scanned with efficient algorithms and huge computing power in order to deduct correlations. The future will show whether this approaches is successful.

2.2.2.5 Conflict Detection

Based on the prediction in the previous step, the conflict detection function is activated. Mostly it is aimed to identify the presence of potential track occupation conflicts, i.e. multiple trains trying to use one of the infrastructure resources (track detection sections) at the same time. These conflicts can be visualised in the blocking time diagram or time–distance graph (Fig. 2.3). For each train the real time–distance graph is displayed until the current time and the prediction in a certain time horizon. Further, the track section occupation times are displayed as boxes around the time–distance line. For conflict-free operation the boxes must not overlap. (Hansen and Pachl 2008)

A train controller used to execute this method by hand utilising a huge amount of expert knowledge. However, nowadays, it is a far more computer-driven process with train controllers still in a responsible role.

Automated conflict detection systems can detect all the types of conflict we have previously considered in this article. Most available algorithms for track conflict detection and resolution work with a sectional, microscopic representation of the infrastructure, like the sequence of track vacancy detection sections a train passes along its run together with its planned occupation and release times (Chen et al. 2010; Corman and Meng 2013; Pellegrini et al. 2014)

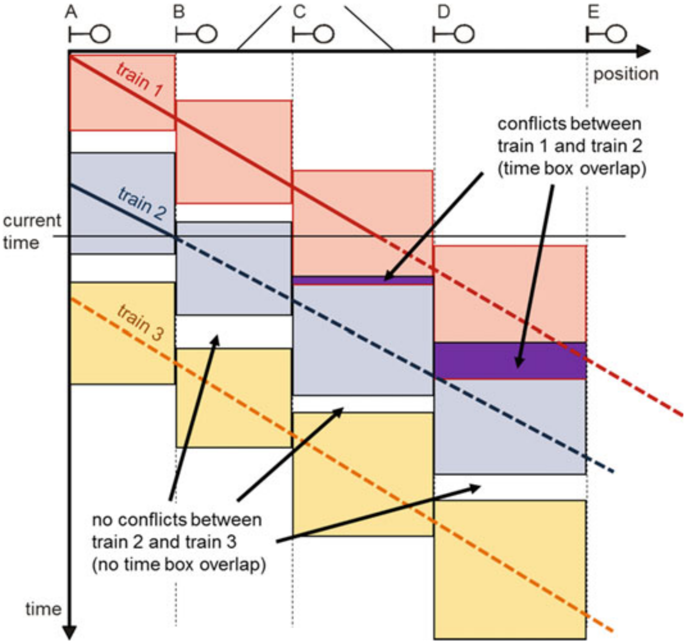


Fig. 2.3 Blocking time diagram with conflict

2.2.2.6 Conflict Solution

Using data from the previous step, solutions can be found to any potential conflict. This real-time conflict detection and resolution in rail has been widely in the focus of the last year's research. Specialised mathematical approaches and algorithms have been described in the scientific literature; see e.g. (Corman and Meng 2013) for a review. They are not in the focus of that article and are however still not applied in daily operation in large railway networks. The measures based on these mathematical approaches can be summarised to five basic classes. These are:

- Reordering;
- Re-timing;
- Re-routing;
- Cancellation of a train;
- Provision of substitute transport.

Re-routing means to allocate alternative tracks in stations or on parallel tracks to the trains. Re-timing means to modify the departures and arrivals at stations. Reordering of trains can happen at junctions or in stations, by cancelling or adding non-commercial stops, e.g. for overtaking purpose. These measures are performed frequently, even in case of slight delays. They do not require any intervention of the RU and are usually summarised under the term perturbation management (Albrecht and Dasigi 2014). More radical measures are the cancellation of trains or the provision of substitute transport on rail or with other transport modes.

Usually, solutions involve one of these measures or a combination of several of them.

2.2.2.7 Implementation

The previously calculated conflict solutions now need to be implemented. This is done by a combination of methods—both track side solutions and vehicle side solutions.

The trackside solutions relay on:

- Disposition assistance systems for changing routes of the trains to avoid, e.g. track occupation conflicts;
- Changing duty sheets or timetables to avoid, e.g. allocation set conflicts or connection conflicts.

On the vehicle side the solutions are automatic train operation systems, which will generate a huge investment, or a Driver Advisory System (DAS), for e.g. speed advises and energy-efficient driving.

In this step, explicit human involvement is necessary due to three important reasons:

- Expert knowledge cannot be completely systemized;
- From legal aspects mostly an human have to take the responsibility;
- Acceptance of assistant systems has to be ensured.

After the implementation in the railway system, the circle closes back to the continuous status detection.

2.2.2.8 Customer Information

One additional step that results from the inner circle of the traffic management is the customer information for both—passengers as well as freight haulier. Communication of any delays or timetable changes to them is absolutely vital. As the customer cannot see the whole process, any changes or measures that affect them must be adequately communicated. From the operator viewpoint, it is better to inform openly than to give space for uncertainties and rumours.

Focussing the passenger transport there are many avenues for communication with passengers in the modern world, e.g. multifunction displays and public address announcement in stations and trains, even online information via websites or apps, message channels or social networks such as Twitter and Facebook. Problems still exist in rural or isolated stations with few systems for communication of delays with passengers. But in general, train operators have few excuses for not providing passengers with accurate information. Besides that, the demand of the passengers to accurate travel information can be described with the triad:

- Information everywhere, e.g. at home, in the train, in stations, especially in connecting stations;
- Information any time when the individual need it, e.g. before and during the journey;
- Information for everyone, independent from the personal abilities of access methods and barriers.

Passengers expect a low-threshold access to up to date information about their trains, connections and journey.

The importance of the passenger information about connections and punctuality to customers can be exemplary shown by the results of a survey among passengers on Dresden’s public transport system (Fig. 2.4)

2.2.2.9 Data

A big bracket around all before mentioned actions (Fig. 2.2) is the use of data and the importance that this data is accurate. Data in that meaning are all information about infrastructure, timetable, rolling stock, resources and operation. Essentially, data is what connects the traffic management cycle to the real world. Without accurate data, the cycle would be useless.

Furthermore, it should be standard to have the information available as open data in open standard formats in the future. Then the exchange of data can be without difficulty between infrastructure managers (IM) and railway undertakings (RU) as well as

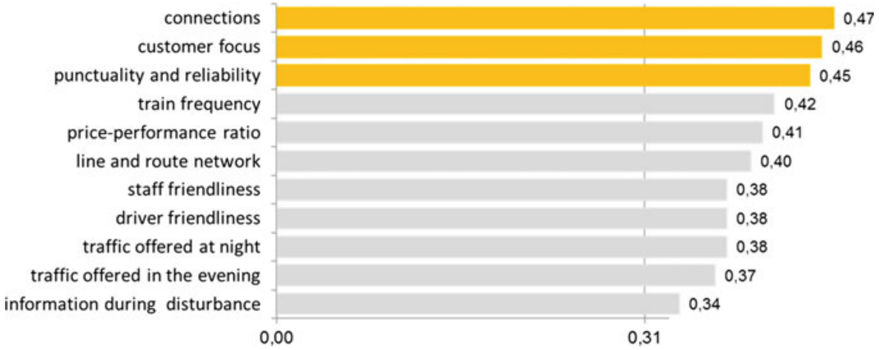


Fig. 2.4 “What is important?”—A survey among passengers on Dresden’s public transport system (*source* TNS Infratest, DVB Kundenbarometer 2012)

between different RUs or different IMs. So the data can be advanced and ennobled by all involved parties, like IM, RU and customers, to open up additional benefits.

2.2.2.10 Quality Control

Quality control is one action in the traffic management cycle that occurs after the focused operation has been completed. This is the step that retrospectively evaluates the actions taken earlier in the cycle. These actions must be constantly evaluated for safety, punctuality, reliability, energy consumption and comfort. Only with this evaluation future responses to problems may be improved and optimised.

In that context, it is clear that traffic management has to be seen in its entirety as a comprehensive task. The cycle, which has been outlined, is an overview of this process.

2.3 Energy-Saving Methods

(By Stefano Ricci)

2.3.1 Effects of Train Driving Methods

Driver behaviour is one of many factors that could potentially reduce energy consumption (Bocharnikov et al. 2007; Chuang et al. 2009; Goodman et al. 1998; Lagos et al. 2000; Matsika et al. 2013; Rodrigue et al. 2006; Spiegel 2009; UIC 2008, 2010; van Essen et al. 2011; Vastels 2009; Wong and Ho 2004; Working Group Railway Noise 2003).

A variety of research projects in the past 15 years been mainly financed by the EU and UIC (e.g. TRAINER, RAILENERGY, ECORAILS) and looked into changes to driver behaviour and how they could reduce energy consumption.

These studies have identified effective measures including using coasting, limiting top speed without coasting and decreasing acceleration, as stated in De Martinis et al. (1999).

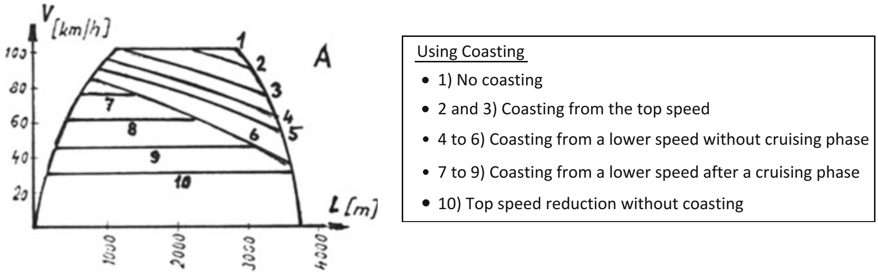
They have also experimented using systems designed to assist the driver in reducing energy consumption by the changing of driver behaviour (see Sect. 2.4).

Work on this sector has shown that the achievable energy saving is anywhere between 10 and 25% (Baldassarra et al. 2011). However, one constraint on this reduction is the possibility of punctuality being penalised.

Coasting and its effect on energy consumption are in Fig. 2.5.

Limiting top speed without coasting and its effect on energy consumption are in Fig. 2.6.

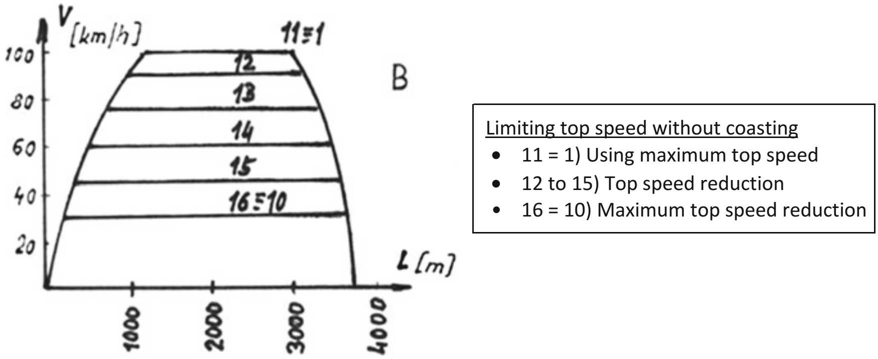
Decreasing acceleration and its effect on energy consumption are in Fig. 2.7. In literature it is hardly discussed whether this measure can really save energy. As De Martinis et al. 1999 mentioned it as probable measure, other authors show that this is not proven by optimal theory or even cannot measured in reality (Fidansoy and Wanjani 2017).



Using Coasting

- 1) No coasting
- 2 and 3) Coasting from the top speed
- 4 to 6) Coasting from a lower speed without cruising phase
- 7 to 9) Coasting from a lower speed after a cruising phase
- 10) Top speed reduction without coasting

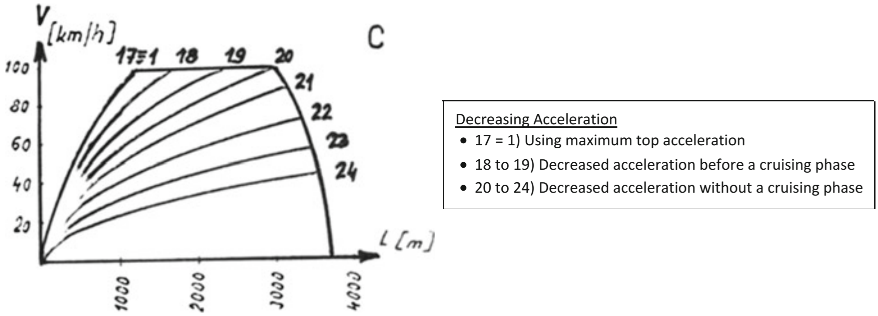
Fig. 2.5 Graph showing relationship between use of coasting and kinematic parameters



Limiting top speed without coasting

- 11 = 1) Using maximum top speed
- 12 to 15) Top speed reduction
- 16 = 10) Maximum top speed reduction

Fig. 2.6 Graph showing relationship between limiting top speed without coasting and kinematic parameters



Decreasing Acceleration

- 17 = 1) Using maximum top acceleration
- 18 to 19) Decreased acceleration before a cruising phase
- 20 to 24) Decreased acceleration without a cruising phase

Fig. 2.7 Graph showing relationship between decreasing acceleration and kinematic parameters

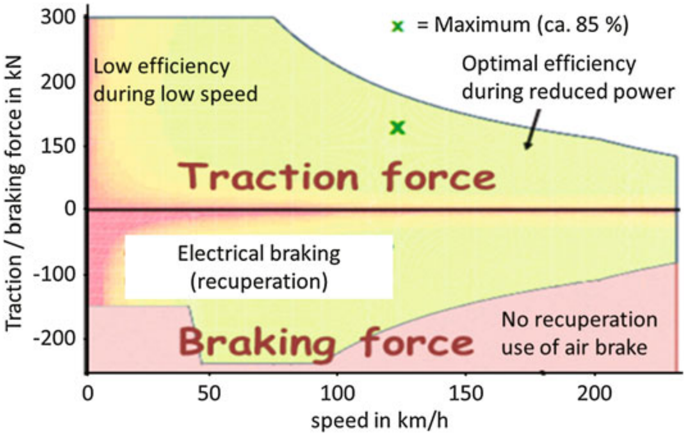


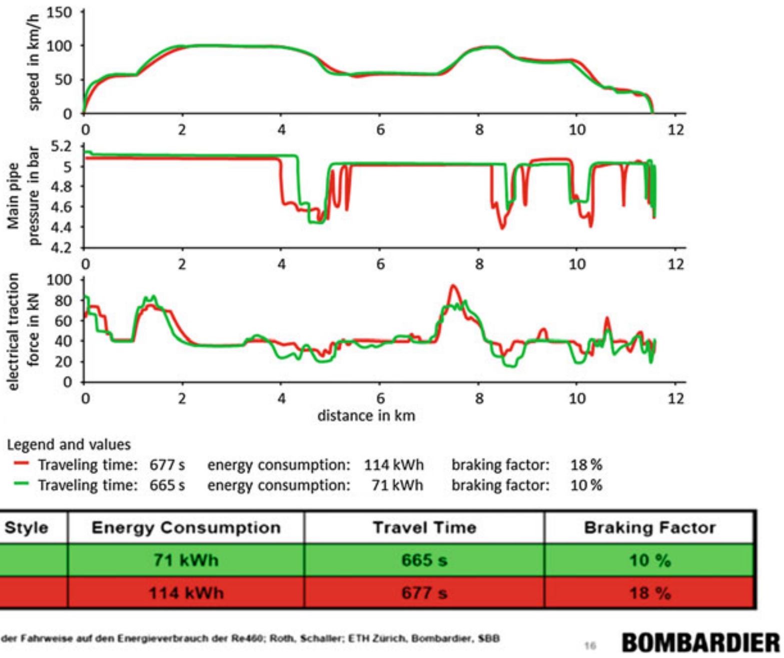
Fig. 2.8 Graph showing relationship between effective use of traction and braking forces and energy consumption (*Source* SBB)

2.3.2 Effective Use of Traction and Braking Forces

Effective uses of traction and braking forces can also lead to a marked reduction in energy consumption.

As shown in Fig. 2.8, a process of minimum consumption on traction and maximum recovery on braking can lead to reductions in energy consumption.

Energetic effectiveness in the graph below increases from red to green areas.



Legend and values
🟥 Traveling time: 677 s energy consumption: 114 kWh braking factor: 18 %
🟩 Traveling time: 665 s energy consumption: 71 kWh braking factor: 10 %

Driving Style	Energy Consumption	Travel Time	Braking Factor
Green	71 kWh	665 s	10 %
Red	114 kWh	677 s	18 %

Source: Einfluss der Fahrweise auf den Energieverbrauch der Re460; Roth, Schaller; ETH Zürich, Bombardier, SBB

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Fig. 2.9 Graphs and table showing comparison of driving styles and their effects on energy consumption and travel time (*Source* Bombardier)

2.3.3 Potential Effects of Driving Style on Energy Consumption

As can be seen in Fig. 2.9, it is possible to alter driving behaviour to reduce energy consumption without compromising on punctuality or travelling time.

It shows a comparison between driving styles on a 12-km section of track with the most energy-efficient option actually taking 12 s fewer.

The sensibility of energy consumption to driving style is clearly emerging from the fact that the driving profile represented in green used 38% less energy with an almost similar, anyway shorter, travel time in comparison with that portrayed in red.

2.3.4 Potential Effects of Driving Style on Travelling Time

However, there are also other possibilities regarding travel time and energy consumption as shown in Fig. 2.10.

It shows a 35% energy reduction is possible with only a 6% longer travel time. A 41-km stretch of track is there used to measure this.

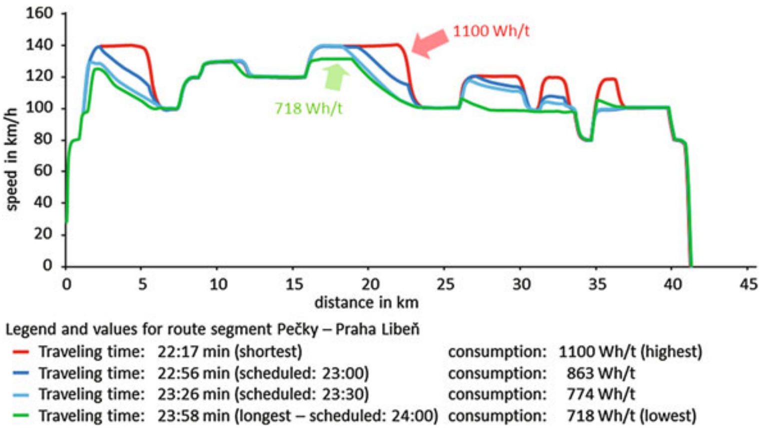


Fig. 2.10 Graph showing effect of different driving behaviours on energy consumption and travel time of a train between Peĉky and Praha Libeň (*source* Ceske Drahy)

This investigation shows that the degree of energy reduction is not wedded to the degree of increase in travel time and that in reality small increases in travel time can lead to huge energy savings.

2.3.5 Vehicles and Fixed Installations Design Affecting Energy Consumption

Vehicles and fixed installations design is another area, where decreases in energy consumption can be found.

Changes assessed during the ECORAIL's project and their potential energy consumption reductions include (Baldassarra et al. 2011; Cosciotti and Ricci 2013; Ricci et al. 2010):

- Braking energy recovery (up to 20%)
  - Supercapacitors in fixed installations or on board (up to 20%),
  - Heating fluids in fixed installation for production of electric power (up to 20%),
  - Use for auxiliary or comfort functions in diesel-electric stock (2–5%);
- Traction energy saving (up to 10%)
  - Energy storage in diesel-electric vehicles (<10%),
  - Common Rail/ modernised diesel engines (<10%),
  - High-temperature superconductor (HTSC)/ Medium frequency transformer (2–13%),
  - Automatic switch-off of traction groups (2–5%),
  - Ventilation control according to actual demand (2–5%);

- Train mass reduction (up to 10%)
  - Double-decked stock or high/low capacity trains (< 10%),
  - Multiple units instead of loco hauled trains (5–10%),
  - Single-axle bogies or consecutive coaches resting on shared bogies (2–10%),
  - Aluminium car bodies (2–5%),
  - Light interior coach equipment (2–5%).

2.3.6 *Energy-Saving Criteria in Mass Rapid Transit (MRT)*

Mass Rapid Transit's typical characteristics include:

- High frequency;
- Short sections between stops;
- Short or absent constant speed sections;
- Cyclic theoretical timetable capable of reducing energy consumption;
- Perturbations of theoretical timetable mainly due to stop times in stations (human factors);
- Perturbations dramatically reducible by full automatic operation.

This study will now explore some relevant aspects of Mass Rapid Transit that could assist in the reduction of energy consumption (Açıkbaş and Söylemez 2008; Albrecht 2004; Antognoli et al. 2005; Chang and Sim 1997; Dominguez et al. 2008; Malavasi 1998; Malavasi et al. 2011; Sansó and Girard 1997).

The adoption of a cyclic timetable with

Acceleration time = Deceleration time = Coasting time = Stop time at stations

would allow an exchange of energy between braking and accelerating trains.

Train 1 braking simultaneously to train 2 acceleration and so on, facilitates the maximum exchange of energy between trains.

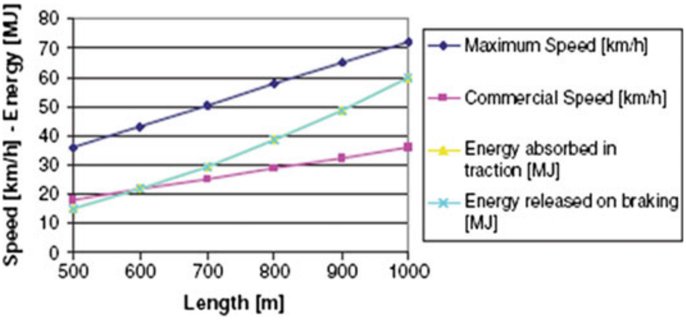


Fig. 2.11 Graph showing effects of section length on energy flows and consumption (*yellow line* is hidden by overlying *light blue one*)

Figure 2.11 shows the almost linear increasing trend of maximum and commercial speeds and the quantity of energy used during traction phases with the increase of the section length: the volume of energy consumed also increases, as the braking phase is less able to compensate for the energy released during the traction phase.

2.4 Driver Advisory Systems (DAS) for Energy-Efficient Driving

(*By Martin Lehnert*)

2.4.1 Motivation for DAS

Driver Advisory Systems (DAS) are part of the railways industries growing move towards automation. They already help railway operators and infrastructure managers to achieve two of their key objectives, safety and punctuality. However there is the third objective where DAS could potentially help with; the economic goal including increased energy efficiency and reduced consumption (Albrecht 2008).

A DAS could potentially provide feedback and support railways to reduce expenditure. It could assist railway undertakings reducing energy consumption by assisting drivers in operating their trains in more energy-efficient ways. Advisory systems could also help infrastructure managers to avoid trains stopping at red signal stops and thus to increase capacity. Such an approach could lead to a significant reduction in fuel and electricity consumption and therefore an increase in energy efficiency and reduction of costs; an outcome which the entire rail industry desires in order to increase its competitiveness with other transport modes (Albrecht 2008).

To provide an overview of DAS the next section focuses mainly on the influence levels of DAS. Then, a further section moves on to showcase some contemporary examples of DAS in action. It will finish by providing some conclusions about DAS and their future use in the rail industry.

2.4.2 DAS on Different Influence Levels

2.4.2.1 Overview

DAS can be grouped by several qualities from which one is the optimization scope. Using this systematisation a DAS for energy-optimal control is related to one of three successional levels:

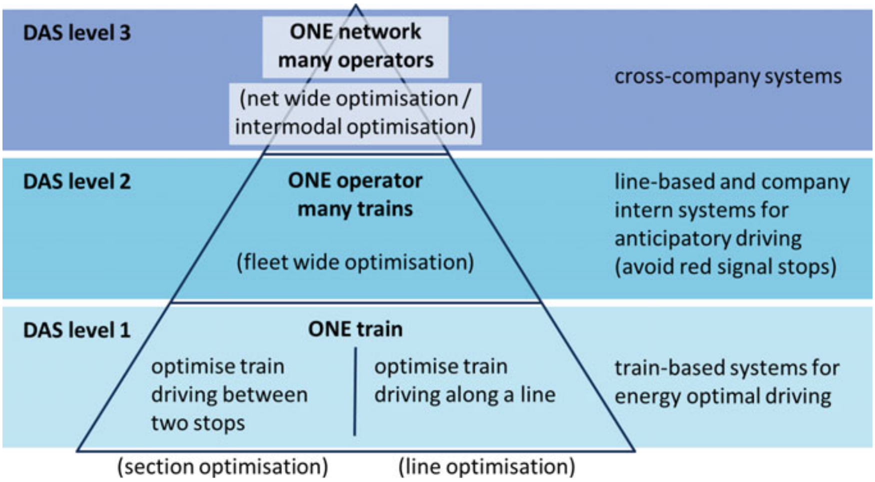
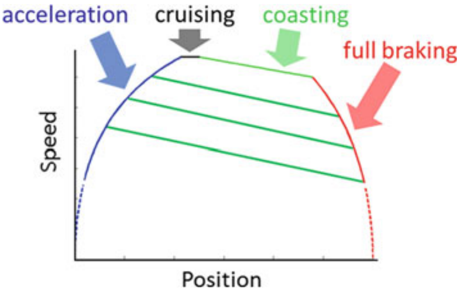


Fig. 2.12 Influence levels for DAS

Fig. 2.13 Regimes for energy-optimal control between two consecutive stations



(1) DAS regarding only one train (DAS level 1);
(2) DAS covering many trains (a fleet) of one operator (DAS level 2);
(3) DAS considering many operators in one network or intermodal optimisation in networks of different transport modes with common connection points (DAS level 3).

The levels are interrelated (Fig. 2.12).

2.4.2.2 One Train Level

A first influence level for DAS is for energy-optimal control between two consecutive stations (section optimisation) and along a line (line optimisation) focusing only on one train.

This follows the theory of optimal control, proven many times over; finding the switchover points between the optimal regimes of acceleration, cruising, coasting and braking that produces the desired running time with the minimal energy consumption (Fig. 2.13). In theory the longer the duration of the coasting phase, the higher the energy consumption reduction possible. The DAS interface would then supply the optimum switchover points to the driver with either an acoustical or visual prompt. This would allow an energy-optimum control between two consecutive stations.

In addition to this first part of optimization between two stops, a second part belongs to the one train level: the optimization of driving and dwell times along a line. As explained in the first part, lower energy consumption would be reached by increasing running time between stations. Nevertheless, the overall running time reserve on a line is limited. Use of different algorithms like dynamic programming can optimally distribute the additional time to the sections of a line. Thereby, the guiding principle is to apply the remaining time to the sections so that delays will be caught up to the next important stations but not necessarily to the next station. In result of that principle and by allowing the DAS to calculate optimum time and speeds in sections it could advise to a train not increasing speed to make up for delays until necessary to arrive on time at an important destination. In total this strategies will again potentially reduce energy consumption.

2.4.2.3 One Operator Level

DAS Level 2 refers to a fleet wide optimisation of one operator's stock (one operator, many trains in Fig. 2.14). This system would promote energy-efficient driving by a line-based and company internal approach for anticipatory driving to concentrate mainly on avoiding red signal stops.

How this system works can be shown with an easy example of the dynamic adaptation of one train's arrival at a crossing station. If a second train from the same operator supposed to cross at the station is delayed, for the first train the opportunity arises to reduce energy consumption. In Fig. 2.14 the train 2 should be delayed. Instead of additional dwell time at a station for train 1, the time can be used to

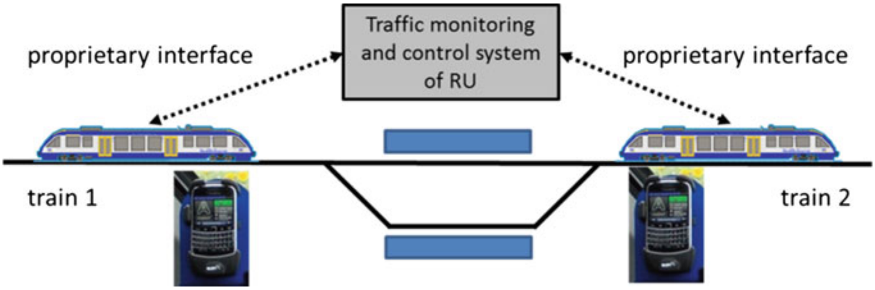


Fig. 2.14 DAS level 2: crossing with delayed train

reduce energy consumption by driving in coasting regime much earlier than in on time conditions. In result the train 1 can also arrive later without negative impact on the crossing process in the station.

On this level, the management and data exchange can be done in the traffic monitoring and control system of the railway undertaking operating both trains.

2.4.2.4 One Network Level

DAS level 3 refers to a network wide and multi operator optimisation (many trains, many operators, one network) or the intermodal optimisation in networks of different transport modes with common connection points, like level crossings, junctions or intermodal connecting stations. In an abstract way, the intermodal network can be seen as a whole via the links and constrains at the connection point.

This level would involve implementation of the system across many operators on the same network. It could also include intermodal operation across different operators and modes of transport. Currently, cross-company systems are not in operation because information from operators is not shared with their competitors.

In the future, open and standardised interfaces that can process information from both infrastructure managers and various railway operators, respectively different transport mode operators, are necessary. This would allow cross-operator anticipatory and energy-optimised driving involving collaboration between various railway operators and the infrastructure managers.

2.4.3 Driving Advices

Driving advices can be presented to the driver in different types and frequencies. It is not efficient to offer drivers huge quantities of advice. Instead, advice provided must be simple and easy to implement. Systems must not show contradictory advice. (Albrecht 2013) The way of giving the information to the driver continuously, but not to overflow him, can be seen as one of the key success factors of a DAS regarding the acceptance of the tool and avoiding the ‘turn it off’ syndrome. The approach of involving humans in the process is called ‘control by awareness’ (Golightly et al. 2013) as antonym to the commonly used concept of ‘control by exception’.

From the practical point of view it have to be pointed out that drivers are the people that will be using the system day to day and they must, therefore, have a large say in any systems design. This is especially the case in situations with strongly unionised employees who could possibly introduce difficulties and delays into implementation of a new system.

Examples of advice that a driver advisory system could show includes advice around optimal departure times from a station and advice around when to switchover from acceleration to coasting while driving along a line. These are the

Table 2.1 Examples for DAS systems with level 1 functions

Developments by universities	Developments by railway undertakings	Developments by railway system suppliers
ENAflexS, InLineFAS by TU Dresden (Albrecht et al. 2013a)	EcoFassi/EcoTrainbook, EbuLa ESF by Deutsche Bahn (Kusche and Geipert 2010; Netz 2005), GreenSpeed by Danske Statsbaner, RCS/ADL by SBB	Trainguard by Siemens (Rahn et al. 2013), EBI Drive 50 by Bombardier (Dischington 2011), LEADER by Knorr Bremse (Fregien et al. 2013), Metromiser/Energymiser by TTG Technology (TTG Technology 2012), CATO by Transrail (Lagos et al. 2000)

kinds of advice that would be useful to drivers and that can be easily implemented. In contrast, it is common sense, not to give an advice for braking. Choosing the right point to brake sufficiently is a safety issue and should be kept in the competences of the driver. Warnings, in case the driver did not react properly, are tasks for automatic train protection (ATP) and equal systems.

2.4.4 Examples and Experiences

DAS systems at various levels are already available on the market. For a comprehensive overview about DAS and their components it is referred to (Panoua et al. 2013). A few systems shall be mentioned in the following to illustrate their theoretical classification.

At DAS level 1, already many systems commercially are available on the market. They are developed by the universities, the national railway undertakings or the railway system suppliers (Table 2.1)

These systems are proven and offer an energy reduction on traction energy, some systems are specialised on and adapted for their use in regional passenger transport, long distance freight transport, heavy rail, light rail or mass transit.

At DAS level 2 some systems are already available. One example of such a system in covering level 2 is the above-mentioned InLineFAS. It is in daily use at Harz-Elbe Express (central Germany) and ODEG (East Germany) since August 2012 and in further RU in different state of implementation. This system has produced a measured reduction in fuel usage of around 5% and a reduction in electrical energy of even more (Albrecht 2008, 2013). These systems have proven to be a success.

DAS level 3 is much harder to implement. There is no implementation known in the railway field. But a first example of a DAS system classified in that level can be named from the intermodal optimisation part. The system called COSEL runs in urban light rail in Dresden, Germany. It focuses on the connection point between the tram network and the street network at shared crossings. There is the tram operator on the one hand and the individual cars and the local traffic light authority as a kind of operator on the other hand. The system optimises multimodal traffic quality by avoiding tram red signal stops at the crossing traffic lights using a DAS in the tram, depending on the current road traffic situation. In fact, that DAS system is installed on the trams only; it can work only in one direction at the moment, from road traffic quality to influencing tram driving. However, the system also uses complementary dwell time for additional reduction of energy consumption by around 4% (Gassel and Krimmling 2013).

2.4.5 Results for DAS

In conclusion, this section has shown the potential benefits of increased use of Driver Advisory Systems. DAS operating at level 1 are widely available on the market; however use of DAS at levels 2 or 3 can open up potential for additional savings. From considering the results of existing implementations, the measured total fuel savings at diesel traction would be around 5% and savings potential at electrical traction could potentially be higher. To achieve further savings, systems must be standardised for cross-company usage.

2.5 Conclusions

Several results emerge from the investigations presented in this chapter.

First, traffic management can be organised on different levels, in which many different conflicts can occur. In terms of conflict solution, many approaches are available and published. But it is clear that traffic management has its entirety as a comprehensive task and the cycle, outlined in this article, is an overview of this process. It can help to promote a common understanding of the topic in the future.

Moreover, the chapter has shown that a variety of factors affect energy consumption. These include driver behaviour, traction and braking forces regulation, vehicles and fixed installations design and timetabling (mainly in MRT). It has also demonstrated that the progressive automation of operation is capable of increasing the effectiveness of these factors by reducing deviations from the best driving style and timetabling. The research into the most effective measures to reduce energy consumption in automatic and manual metro operations led more light upon this important topic. However, while discussing the finer details of the railway industries push for reduced energy consumption one must also remember and reflect upon the importance of this task being realised both for economic objectives.

As one important measure Driver Advisory Systems has been focused in the chapter and the potential benefits of their increased use has been shown. The systems can be systemised in three levels regarding the influence range. While systems on level 1 are widely developed and used, further applications of level 2 systems and the implementation of level 3 systems can open up potential for additional savings. Therefore, systems and interfaces must be standardised for cross-company usage. However, DAS must be optimised to suit train drivers as they would decide about the daily DAS use at the end. The section has shown the potential for increased development of DAS and building on this work, further studies on the potential for implementation of these systems are expected.

References

Açıkbaş S, Söylemez MT (2008) Coasting point optimisation for mass rail transit lines using artificial neural networks and genetic algorithms. IET Electr Power Appl 2(3):172–182

Albrecht T (2004) Reducing peaks and energy consumption in rail transit systems by simultaneous train running time control—Computers in Railways IX. WIT Press, Southampton

Albrecht T (2008) Energy-efficient train operation. In: Hansen IA, Pachl J (2008) Railway timetable & traffic, Eurailpress. DVV Media

Albrecht T (2013) Human factor challenges in the development of a Driver Advisory System for regional passenger trains. In: Dadashi N et al (eds) Rail human factors: supporting reliability, safety and cost reduction, Taylor & Francis, pp 129–138

Albrecht, T, Dasigi M (2014) ON-TIME—A framework for integrated railway network operation management. In: 5th Conference Transport Research Arena TRA 2014, Paris

Albrecht T, Binder A, Gassel C (2013a) Applications of real-time speed control in rail-bound public transportation systems. IET Intel Transp Syst 7(3):305–314

Albrecht T, Lüddecke K, Zimmermann J (2013b) A precise and reliable train positioning system and its use for automation of train operation. In: IEEE international conference on intelligent rail transportation (ICIRT), Beijing

Antognoli M, Malavasi G, Ricci S (2005) Operation automation level in an underground line and service reliability. Railway Operations Modelling and Analysis, Delft

Baldassarra A, Cosciotti E, Ricci S (2011) Energy Efficiency and Environmental Criteria in the awarding of railway vehicles and services: methodologies of implementation and monitoring. World Congress on Railway Research, Lille

Binder A, Albrecht T (2012) Predictive energy-efficient running time control for metro lines. In: CASPT12—conference on advanced systems for public transport, Santiago de Chile, Chile

Bocharnikov YV, Tobias AM, Roberts C, Hillmansen S, Goodman CJ (2007) Optimal driving strategy for traction energy saving on DC suburban railways. IET Electr Power Appl 1(5):675

Chang, CS, Sim SS (1997) Optimising train movements through coast control using genetic algorithms. In: IEE Proceedings—Electric power applications, vol 144, no 1, p 65

Chen L, Schmid F, Dasigi M, Ning B, Roberts C, Tang T (2010) Real-time train rescheduling in junction areas. In: Proceedings of the institution of mechanical engineers, Part F: J Rail Rapid Transit 224(6):547–557

Chuang HJ, Chen CS, Lin CH, Hsieh CH, Ho CY (2009) Design of optimal Coasting speed for MRT systems using ANN models. IEEE Trans Ind Appl 45(6):2090–2097

Corman F, Meng L (2013) A review of online dynamic models and algorithms for railway traffic control. In: First IEEE international conference on intelligent railway transportation, Beijing

Cosciotti E, Ricci S (2013) Simulation and functional requirements of energy efficient driving. In: IAROR conference rail, Copenhagen

De Martinis V, Gallo M, D'Acierno L (2013) Estimating the benefits of energy-efficient train driving strategies: a model calibration with real data—Urban Transport XIX. WIT Press, Southampton

Dischington S (2011) Energy savings with ERTMS Level 3—EBI Drive 50 driver assistance system. In: ERESS Customer Forum 'Energy Efficiency—Smart Metering & Billing', Brussels

Dominguez M, Fernández A, Cucala AP, Cayuela LP (2008) Computer-aided design of ATO speed commands according to energy consumption criteria—Computers in Railways XI. WIT Press, Southampton

Gassel C, Krimmling J (2013) Effects of cooperative traffic signals on Tramway operation. In: Proceedings of the 3rd international conference on models and technologies for intelligent transportation systems, Dresden, TUD Press, pp 301–310

Golightly D, Sandblad B, Dadashi N, Andersson AW, Tschirner S, Shaples S (2013) A sociotechnical comparison of automated train traffic control between GB and Sweden. In: Dadashi N et al (eds) Rail human factors—Supporting reliability, safety and cost reduction. CRC Press

Goodman CJ, Siu LK, Ho TK (1998) A review of simulation models for railway systems. In: International conference on developments in mass transit systems, London, Conference Publication no. 543. OIEE

Fidansoy Y, Wanjani S (2017) Design Thinking bei der Anwendung der energiesparsamen Fahrweise. EI – Der Eisenbahningenieur 68(2):42–44

Fregien G, Paddison J, Beck M, Kock G (2013) Zeitgemäße Güterwagenausrüstung für hochwertige Transportaufgaben - 41. Tagung Moderne Schienenfahrzeuge, Graz

Hansen IA, Pachl J (2008) Railway timetable and traffic. Eurailpress, Hamburg

Jaekel B (2013) Einfluss von Massemodellierung und Algorithmenwahl auf Fahrdynamikrechnungen - 47. Regelungstechnisches Kolloqium, Boppard, Germany

Kusche M, Geipert S (2010) Ecotrainbook—Driver assistance system. In: 11th UIC sustainability conference, Madrid

Lagos M, Hellström P, Leander P (2000) Computer-aided train operation: CATO—Computers in Railways VII. WIT Press, Southampton

Malavasi G (1998) Analysis of rail rapid transit systems by means of simulation models—Urban Transport IV. WIT Press, Southampton

Malavasi G, Palleschi P, Ricci S (2011) Driving and operation strategies for traction-energy saving in mass rapid transit systems. In: Proceedings of the institution of mechanical engineers. Part F: J Rail Rapid Transit 225(5):475–482

Matsika E, Ricci S, Mortimer P, Georgiev N, O'Neill C (2013) Rail vehicles, environment, safety and security. Res Transp Econ 41(1):43–58

Netz M (2005) Technische Assistenzsysteme der Deutschen Bahn unterstützen Energie sparendes Fahren. ETR - Eisenbahntechnische Rundschau 54(10):595–598

ON-TIME (2012) Deliverable D1.1—Principles, definitions and requirements—ON-TIME project EU FP7-SCP0–GA–2011-265647, Deliverable ONT-WP01-DEL-001

Pellegrini P, Marlière G, Rodriguez J (2014) Optimal train routing and scheduling for managing traffic perturbations in complex junctions. Transp Res Part B 59:58–80

Panoua K, Tzieropoulos P, Emery D (2013) Railway driver advice systems: evaluation of methods, tools and systems. J Rail Transp Plann Manag 3(4):150–162

Rahn K, Bode C, Albrecht T (2013) Energy-efficient driving in the context of a communications-based train control system (CBTC). In: IEEE International conference on intelligent rail transportation (ICIRT), Beijing

Ricci S, Cosciotti E, Baldassarra A (2010) Integration of technological feedback from the User Platform and the consortium into the guidelines. ECORailS Project, Deliverable 7. www.ecorails.eu

Rodrigue JP, Comtois C, Slack B, Rodrigue J (2006) The geography of transport systems. Taylor & Francis, New York

Sansó B, Girard P (1997) Instantaneous power peak reduction and train scheduling desynchronization in subway systems. Transp Sci 31(4):312–323

Spiegel B (2009) Energy metering an overview of the complete system. Energy Efficiency days 2009, Tours

Standard EN ISO 9000:2015 (2015) Quality management systems—Fundamentals and vocabulary

TTG Technology Limited (2012) ENERGYMISER®—Reduce energy bills, emissions and maintenance–Improve on-time arrivals. Product leaflet

UIC (2008) CER—Rail transport and environment. Facts & Figure

UIC (2010) UNIFE—Technical Recommendation 100_001. Specification and verification of energy consumption for railway rolling stock

Van Essen H, Schroten A, Otten M, Sutter D, Schreyer C, Zandonella R (2011) External costs of transport in Europe. Update study for 2008. CE Delft, Infras, Fraunhofer ISI, Publication code 11.4215.50

Vastel D (2009) SNCF energy savings program. Energy Efficiency Days 2009, Tours

Wong KK, Ho TK (2004) Coast control for mass rapid transit railways with searching methods. In: IEE Proc Electric Power Appl 151(3):365

Working Group Railway Noise (2003) Position Paper on the European strategies and priorities for railway noise abatement. European Commission, Luxembourg