



ACTUATE

Advanced training for safe and economic driving of electronically powered vehicles

– Tram –

www.actuate-ecodriving.eu

Co-funded by the Intelligent Energy Europe Programme of the European Union

actuate

ACTUATE

A project for optimising the driving performance for reduced energy consumption

Training programmes and general training measures for the economic driving of electronically powered vehicles in the public transport sector (PT) were developed, tested and successfully introduced within the framework of the European-sponsored project ACTUATE.

The introduction of advanced training for economic driving, the energy-saving potential of electronically powered vehicles such as trams, hybrid buses or trolleybuses can be further optimised and thus, the cost-effectiveness and wide distribution of this vehicle type can be promoted.

The project ACTUATE places particular focus on the driver as the pivotal element for economic driving. Accompanying motivational campaigns will also ensure that drivers apply what they have learned in the advanced training sessions in the long-term.

A project to optimise driving behaviour...

- for safe economic driving of electronically powered vehicles in the public transport sector (PT)
- to increase the cost-effectiveness of electronically powered vehicles in the public transport sector through
  - developing and testing trainings programmes for safe and economic driving
  - motivational campaigns for drivers of trams, trolleybuses, hybrid buses

This training brochure has been developed for the vehicle type tram within the framework of ACTUATE.

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1 Introduction

Why save energy? Energy has become a precious resource. Oil will not last forever as a source of fuel. Although vehicles with diesel or petrol engines have become significantly less polluting than just a few years ago with catalytic converters, particulate filters and other systems, nevertheless they still pollute the environment. Therefore we have to consider alternatives. Electricity is a clean alternative.

However, here, too, there are different methods of generating electricity. One method is the still widespread use of coal-fired power stations. But coal will not last forever; furthermore, contaminants are created when generating electricity and these pollute the environment. Therefore electricity is being produced to an increasing extent using eco-friendly, renewable energies, such as wind, sun or water power. This method of generating electricity is 100 % environmentally-friendly and its importance is growing.

However, until all our electricity needs can be satisfied using renewable energy, a host of problems remains to be resolved. Firstly, once electricity is produced it must be brought from the production site to the consumer. The power networks have to be extended correspondingly. Secondly, a stable supply of electricity is needed, since the wind does not always blow and the sun does not always shine. Hence storing electricity until it is needed is a challenge. There are not yet enough pumped storage power stations to store electricity.

Electricity is a precious commodity and our lives today are impossible to imagine without it; therefore we must be aware of our behaviour and be careful when using existing resources in our private lives as well in the public sphere. Local public transport has a special role to play as a model. Modern technology and ecodriving practised by drivers can make a significant contribution to saving energy.

All rail vehicles that feed their braking energy back into the traction grid help us to lower energy consumption.

Eine Straßenbahn vom Typ NGT 8 vor dem Neuen Rathaus in Leipzig

Der Fahrer macht den Unterschied!

1.1 Ecodriving

Ecodriving can, of course, be transferred not only to trams but also to other "clean" vehicles such as light rail vehicles, underground railways, trolleybuses, electric buses and also to hybrid bus technology. The principles for optimum driving must therefore be formulated as follows:

Safety — *Cost-effectiveness* — *Punctuality* — *Customer orientation*

But what does this mean in detail?

Safety
Safety is the first priority. Everything else must be subject to safety! Safety, or security, is derived from the Latin word "sÐcÐritÐs", which means "providence" or "without care". It describes a condition considered to be free of danger. Passengers should board a local passenger train "without care" and it should bring them to their destination in a "careful" manner. Ecodriving always means anticipating when driving, the be-all and end-all for safety in road traffic.

Cost-effectiveness
Cost-effectiveness is a general measure of efficiency and sensible use of resources. The aim is also to use as little energy as possible to get from A to B. Furthermore, a balanced, well thought-out, energy efficient mode of driving minimises wear on vehicles and infrastructure (tracks and overhead line systems). Energy saved means money saved!

Punctuality
Customers expect punctuality from their public transport system. Services should never leave stops too early. Underground rail systems can remain punctual without a problem because they operate in a closed system undisturbed by other traffic. Unfortunately it is often the case that trams and, to an extent, light rail systems cannot avoid delays in their journeys, due to the fact that they operate alongside individual means of transport.

Many people place their trust in their local public transport system daily.

Punctuality should never be enforced at the expense of less safety (taking risks when driving). Imprudent driving at high speeds not only poses a risk to safety but also increases wear on vehicles and infrastructure.

Economic and anticipatory driving is not synonymous with longer journey times, as proved by experience garnered in practi-cal sessions of the training courses on ecodriving offered in partner cities in the ACTUATE project (e.g. in Brno, Czech Republic, for trams or Salzburg, Austria, for trolley-buses).

Customer orientation

Customer orientation is an important tool for transport companies when creating their public image. Customer orientation is often called customer service. It means satisfying customers' wishes regarding the "passenger transport" service. This is complemented by services such as helping passengers with limited mobility when boarding or exiting vehicles or providing information on the price of tickets, etc.
Our customers want to deal with competent employees and not stressed, exhausted drivers who react to a question with a dour grumble. They want to feel safe and secure (see safety).

A driver who uses a balanced, economic way of driving is less stressed and can respond better to customers (passengers). Drivers and passengers feel more at ease and more secure with a gentler, more economic way of driving.

Who benefits from ecodriving?

The driver

The driver is more relaxed and less stressed while driving.

The passenger

The passenger feels safer because s/he senses the calmness of the competent driver through their anticipatory and gentler way of driving.

The infrastructure

The infrastructure is subject to less stress with an anticipatory and gentler way of driving, resulting, for example, in less wear on points and track intersections. In the long term this means significant savings in infrastructure costs.

The vehicle

Utilising rolling of the vehicle means it runs more smoothly and is subject to less stress, for example with less wear on the rim-tyres or less wear on the electronic control system (anti-slip and anti-slide protection).

First overhead line developed by W. v. Siemens

The company

The company will save a lot of money in the long term through lower energy consumption, fewer repairs to vehicles and infrastructure and possibly lower personnel costs because less sick days can be expected, and hence there will be a higher availability of personnel, resulting from less stress through ecodriving and consequently greater employee satisfaction.

1.2 Electrical vehicles – past and future

Electrically powered vehicles are actually older than cars powered by fuel. The Frenchman Gustave Trouvé built the first electric vehicle and drove it through Paris in 1881.

It was a three-wheeler with lead-acid batteries and an electric motor. It had a top speed of 12 km/h with a range of 14-26 km. The first electric car in Germany was built by the Coburg based machine works A. Flocken in 1888. It was the first four-wheeled electric car. The first fuel-powered car was developed by Karl Benz in 1886. Electric trams were first built in 1881.

With the overhead line developed by J.C. Henry in 1884, which was very similar to the ones in use today, tram networks could be expanded. Although trams were replaced by buses in many cities in Europe throughout the 1950s, they are now experiencing a renaissance in many cities in Europe (especially France). The advantages of electrically powered vehicles have found general recognition.

They are cleaner and quieter than petrol or diesel powered vehicles. Equipped with new traction systems with regenerative brakes (regenerative brake = energy from braking is fed back into the traction grid) they are much more efficient and more cost-effective in operation.

As a means of mass transport in large cities, all rail vehicles offer the advantage that substantially more passengers can be transported than by bus. If these vehicles are also powered using green energy, then trams, light urban railways and underground railways are the cleanest and most environmentally-friendly means of transport available.

„eco driving": entspannter und stressärmer durch ausgeglichene Fahrweise

How else are you supposed to save if not intelligently?

Christiane „Tissy“ Bruns (journalist)

2 Factors influencing energy consumption

But despite all the general advantages given above and the cutting-edge technology, rail vehicles must ideally be operated so that they consume as little energy as possible because electricity generation is expensive. Converting to green electricity entails additional costs. An economic, energy saving way of driving is subject to several factors. There are exterior factors that **cannot** be influenced by drivers. These include the condition of the tracks, the conditions of rim-tyres, the traffic density, topography, type of vehicle (motor rating), occupancy of the vehicle and of course whether the vehicle is fitted with a regenerative brake. However, there are factors that can certainly be influenced by drivers. These include a **consciously energy-saving manner of driving**, i.e. considering when accelerating makes sense and when it does not. This is called simply **anticipatory driving**.

We should be constantly asking ourselves the following questions when driving and answer them honestly:

- Does it make sense to always select the highest acceleration on starting if the condition of the tracks is not the best?
- Will I really save time if I accelerate with the highest theoretical value/ highest acceleration on starting but then have to brake to a halt at a stop signal?
- Do I have to increase speed if there are points a short distance ahead that I can only cross at a slow speed?

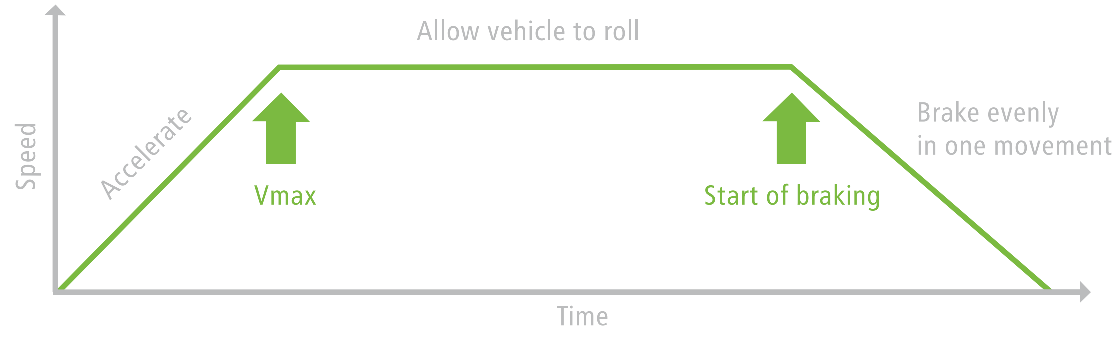
To be honest, we can answer all these questions with a clear “**NO**”. On upgrades you need to consider whether holding a constant speed with low energy consumption should be selected or whether to accelerate and roll alternately. The gradient of the upgrade and the control system of the vehicle need to be considered.

The following is an example of efficient driving: If a stop that has been served is followed at around 30 m by a set of points that can only be crossed at 15 km/h, acceleration to a maximum of c. 18 km/h (assuming the line is straight) is sensible. Allow the vehicle to roll over the points and then accelerate after the points according to line conditions. When the required speed has been reached, utilise the option to roll and brake evenly at the next stop.

Blick aus dem Cockpit auf eine modernisierte Trasse

2.1 The human factor

Ideal route



Drivers must understand that an adaptive, energy-saving manner of driving is to their own advantage. The ideal driving curve in town without significant upgrades or downgrades would be: select a high, but even, rate of acceleration adapted to the weather, traffic and track conditions until the desired or permitted maximum speed is reached, allow the vehicle to roll and then brake evenly to come to a standstill, with a fairly long braking distance, i.e. average nominal value / medium braking level, giving consideration to passengers. This driving behaviour applies to vehicles both with and without regenerative brakes.

Vehicles fitted with an energy recovery system have the advantage that if a longer braking distance is selected, energy is fed back into the traction grid for a longer time. If a vehicle can feed braking energy back into the network, in most transport companies it is fed into the busbar in the substation and can be used on all routes connected to the busbar. This means it is possible that energy regeneration can be utilised to almost 90 % by other accelerating vehicles. Energy recovery cannot be used as intensively in the early hours of the morning or late at night when the intervals between vehicles are further apart. However, energy storage devices have already been developed that can be installed in substations so that regeneration energy can be used during slack periods.

Each company must calculate whether the expense and benefits are worthwhile. The same applies to energy storage devices in vehicles which can also store energy on an interim basis; however they increase the axle load and so may impact negatively on the infrastructure. Irrespective of whether there are storage devices in substations or not, the fact remains that if the traction grid cannot absorb the energy, the energy from braking is dissipated by the vehicle through resistance.

There are still some cities in Europe where you will find vehicles fitted with rheostatic control. The highest possible acceleration rate appropriate to the line and adhesion should always be selected in order to turn off the resistors quickly (for explanation see 3.1).

Generally it can be said that ideal ecodriving behaviour can be implemented best on a separate or special track formation.

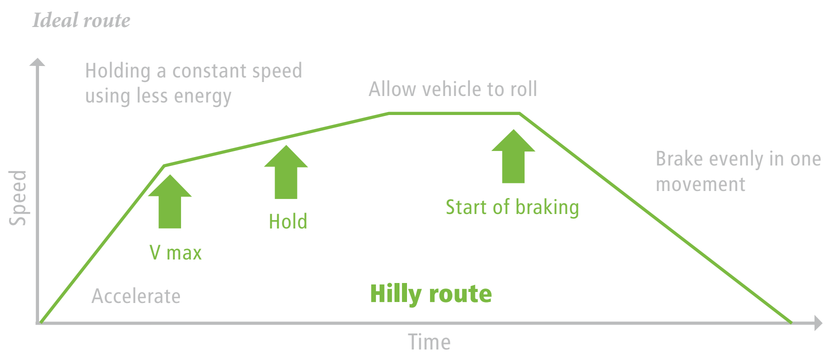
If a tram has to travel through personal motorised traffic, constantly fluctuating traffic situations occur which prevent the driver from adhering to the "ideal driving curve". Anticipatory driving behaviour is the only thing that helps in order to comply as far as possible with the ideal driving pattern. You should also think of yourself because if you are calm inside, you will show calm driving behaviour, drive in a relaxed manner and hence will be stress-free.

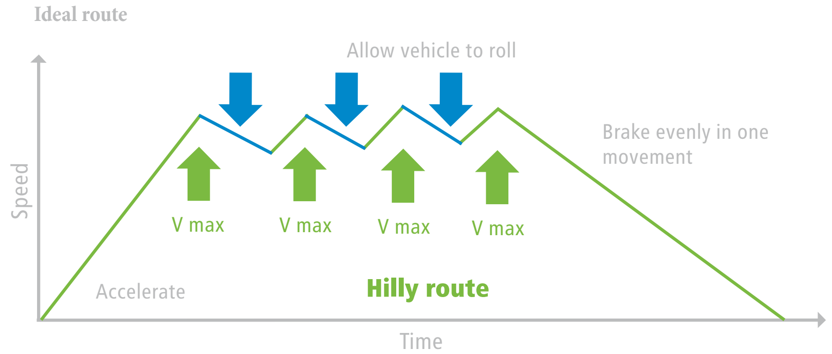
To extrapolate, a proactive approach to all situations and a '"good helping" of calmness can help to save a lot of energy, not only in terms of kW/h but also in terms of the driver's nerves.

2.2 The infrastructure and topography factors

The factors that cannot be influenced in relation to implementing ecodriving behaviour include the topographical conditions in a town (steep upgrades and downgrades) and - from the driver's point of view - the construction of the tracks (a separate track formation or tracks laid in the road surface).

For tram networks in hilly towns there are two different "ideal driving curves" for upgrades, depending on the vehicle control system. In vehicles with a type of cruise control it is economical to remain in a certain position of the





setpoint device or accelerator in order to maintain the speed at the required level using little electricity. This would be particularly effective if a vehicle would also have to travel downhill, constantly applying the brakes lightly. The regen electricity could be used fully by vehicles travelling downhill.

This presupposes, of course, that vehicles are fitted with regenerative brakes. If the vehicle is only fitted with a simple rheostatic brake, the energy from braking is dissipated via the rheostats as, for example, is the case with the acceleration control in a Tatra that has not been upgraded or in vehicles with additional resistance. In these types of vehicles it is better to accelerate fast and hard so that the resistance can be cut out quickly and the traction current can be fully utilised by the motors (see vehicle control systems 3.1).

Which driving curve is ideal on hilly routes also depends on the length of route, the permitted speed and, as has been mentioned several times, on the vehicle control system. Therefore the best driving curve on tracks incorporated into the road surface for a specific situation can be better found through anticipatory driving behaviour and a good knowledge of the route.

It is always easier to adhere to the ideal driving curve in underground railways and light rail systems on routes with train control not "disrupted" by personal motorised traffic. It is here that optimum timetabling can have a positive effect on energy consumption (for example by allowing for intersections, for signals to be switched, etc.).

2.3 The routes and rolling resistance factor

Traction...

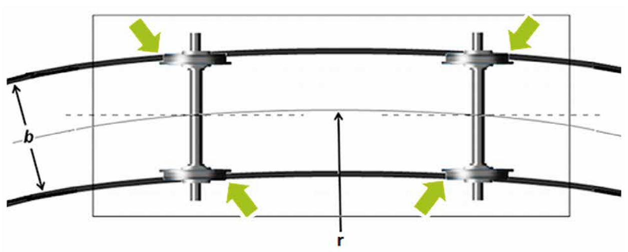
... is necessary to generate and maintain the status of movement.

... works against inertia and resistance forces.

... is dependent on sufficient wheel – rail frictional connection.

The force F may not exceed the maximum adhesion coefficient (wheel-rail frictional connection) because otherwise the wheels would slip or slide. Different positive and negative forces and resistances are always acting on the vehicle in terms of vehicle dynamics. In terms of the characteristics of the route, these comprise the inclined plane force, curve resistance and resistance of points.

Inclined plane resistance should be understood as meaning the topographic conditions. The inclined plane resistance converts potential into kinetic energy and vice versa.



The inclined plane resistance or inclined place force can retain energy (downhill) or obstruct energy (upgrade). Gradients are measured in ‰ (per mille). Curve resistance refers to the wheelsets rubbing on the head of rail. This can cause the wheels to slide, caused by the different distances to be travelled by the low side and the high side of the wheel.

In contrast to a motor vehicle, the wheels on a tram are attached rigidly to the axle. In a curve the wheel flange is oblique to the groove or presses against the head of rail. The smaller the radius within the curve, the greater the resistance. This causes the typical screeching which today can be lessened through stationary curve lubrication devices or train-borne wheel flange lubrication. Points resistance is low so it can be ignored for calculation purposes. It comprises buffets and friction between wheels and check rails or frogs in the points. In addition to line resistance, there are further forces that are caused by the vehicle itself. These are starting resistance, air resistance and rolling resistance. Starting resistance is caused by physical inertia.

“An object at rest tries to stay at rest.” This was expressed by Sir Isaac Newton in 1687 and formulated in his Law of Inertia. In relation to the dynamics of vehicle movements this means that the force originating from the motor has to overcome various “inner resistances”, for example gear train, various bearings and the force of wheel/rail contact before the vehicle starts to move (force = mass x acceleration).

Air resistance is the force the vehicle must exert in order to displace air. Air resistance increases fourfold with speed. Since trams normally do not have an aerodynamic shape, their air resistance is higher than is the case with high speed trains such as Thalys, ICE or TGV which have a very streamlined design. However, air resistance does not play such a major role at the relatively low speeds at which a tram travels on average. The last resistance is rolling resistance.

If we compare the wheels of a tram or of any rail vehicle in general with those of a motor vehicle, we notice immediately the small bearing surface of the wheels in rail vehicles. This has the advantage of very low rolling resistance.

After accelerating briefly, the rail vehicle will roll at a nearly unchanged speed for very long distances on a level line. This is one of the most important facts of ecodriving. However, a car tyre has broad contact with the road surface. If you were to let a car run in neutral/freewheel on a level road, it would lose speed considerably faster than a tram due to the high rolling friction between road and tyre. This is compounded by the materials which come into contact with each other. The smooth surface of the steel wheel and steel rail also ensure low rolling friction.

Der Rollwiderstand von Schienenfahrzeugen ist durch die geringe Auflagefläche der Räder sehr niedrig.

In contrast, the non-slip rubber adheres well to the rough asphalt, which is an advantage when braking. However, in a tram the small bearing surface means that it starts to slip quickly if the relevant parameters are not considered properly. New rim-tyres or ones that have just been refurbished are still slightly oblique and a new head of rail is slightly arched which further reduces rolling friction, but also reduces adhesion.

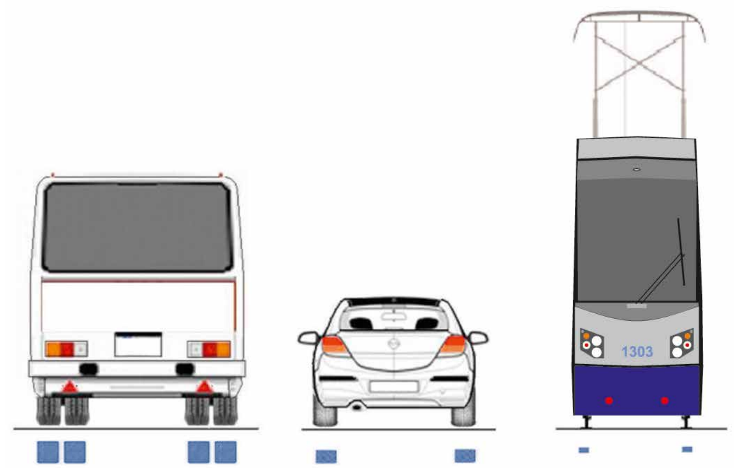
The so-called “intermediary media” are also of major importance. If there is sand on the rail, this has an arrestive effect, the friction between wheel and rail increases, the vehicle starts easily and does not start to slip when braking. In new vehicles the driver does not have to activate the sander; instead it is activated automatically by the electronic control system when it detects differing speeds of revolution of the axles in the motor bogie or running gear.

Of course the driver can and should make conscious use of the sander. For example, if it is clear when approaching a stop that the rails are black from freshly spread asphalt, the driver should actuate the sander on applying the brake and not wait for the electronics to respond. Fallen leaves, pollen and similar materials also reduce adhesion considerably, causing the vehicle to start slipping more readily when braking and the wheels to slip on starting.

However, compensating poor adhesion through the electronic slip and slide protection has a disadvantage in that it is activated as soon as the axles show very small differences in their speed of rotation. This automatically means sand is spread on points. The points become clogged with sand, cannot be moved by electric power and have to be cleaned more frequently.

These types of situation should also be considered because the appropriate action will also save electricity. If the points cannot be moved by electric power the driver must stop, move the points by hand and start off again. This disrupts the journey. More electrical power is needed to start off again and time is lost which again results in stress. So it is always better if you can roll over the points without interrupting the journey.

Excess sand in the points must be avoided to ensure an uninterrupted journey. Therefore, in normal circumstances (i.e. no danger) you should allow the vehicle to roll over the complete points in neutral.



Vergleich des Rollwiderstand: Bus, Kfz und Straßenbahn

When rolling the vehicle will not scatter sand because the wheels will neither slip nor slide. These are small actions but taken as a whole even such small actions are worth considering.

In older vehicles the driver must prevent slipping and sliding by manually actuating the sander in good time. Slipping and sliding also results in high wear on wheels and rails. Slipping increases wear on rim-tyres, sliding causes wheel flats so wheel bandages have to be adjusted.

The rails are subject to more wear in both cases. These are all costs which can be avoided with intelligent, anticipatory driving behaviour.

2.4 The role played by speed

Speed and braking distance have an inseparable reciprocal effect on each other. When selecting speed, various other factors must be considered in addition to the line and vehicle resistances described above.

For example, visibility, occupancy of the vehicle, traffic conditions and the individual skills of the driver. Speed must be selected not only to ensure that control is kept over the vehicle at all times but also to ensure that the vehicle can be stopped in time and without risk, in every situation.

The braking distance itself is also influenced by several factors. For example, speed, condition of rails, line conditions, traction or the addition of a trailer vehicle and the type of braking system play a role that should not be underestimated. The most important factor is speed because the braking distance increases fourfold with speed. Put simply this means:

"If you double speed, you quadruple your braking distance."

If we look at the overall stopping distance, we must add the response time of the driver because the overall stopping distance is the response distance plus braking distance.

If the driver has a response time of 1 second, s/he will travel 13.9 metres at a speed of 50 km/h. Just bear that in mind. If a driver is distracted by something and loses concentration for only 3 seconds, this means the tram will travel "blind" for 41.7 metres through traffic.

If you double speed, you quadruple your braking distance.

Das Leipziger Streckennetz umfasst insgesamt 319,1 km.

In Leipzig werden 98 % der zurück gespeisten Energie genutzt!

3 Vehicle control and energy supply

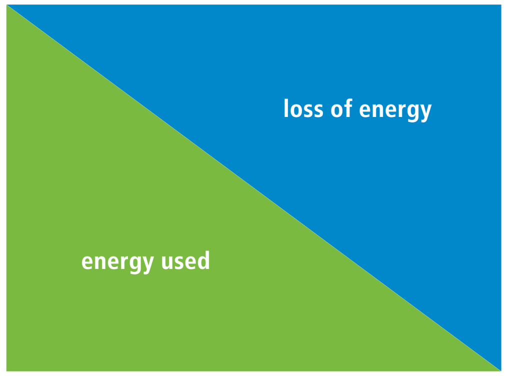
Why is the control system for rail vehicles so important? Tram power supply systems are DC systems. A chopper, for example, is a low-loss control method for electric motors (see 3.1.1). Choppers offer a higher efficiency factor for control. When braking energy can be recouped through regeneration and is fed back into the traction grid.

In order to save even more energy some tram manufacturers have developed energy storage devices in order to store braking energy when the traction grid cannot absorb the energy. Double-layer capacitors (DLC) or batteries are installed in the vehicles.

During the acceleration phase the motors can extract electricity from the storage devices and the capacitors are recharged with regenerative energy during braking. This is an excellent way of using energy 100% but costs are still very high. Whether this technology is really worth the cost depends largely on the existing traction grid, the intervals between vehicles and the degree of utilisation of the energy fed back in.

3.1 Vehicle control systems

The different vehicle control systems must also be included when considering ecodriving behaviour. As already described in the section on infrastructure and topography, rheostatic control is the least economical form of control.



In order for the traction current to be fed slowly into the traction motors, it flows through resistors (series resistors) which are switched off in succession until the motors are fed by the full traction current.

In earlier times this was done manually using a crank or ratchet mechanism. Electricity is converted to heat in the resistors. Only about 50 % of energy absorbed is actually used. Often fans have to be used to cool the resistors. Often field weakening control is used to increase speed. Field weakening or shunting (=switching in parallel) is a resistor which, after switching off all series resistors, is switched to run parallel to the field of the relevant traction motor (2 resistors are also possible, switched in parallel one after the other).

The intensity of current of the main field is divided at the traction motor, while the armature current is maintained at full strength. This weakens the magnetic field of the main field coils while the armature retains its strong magnetic field. The result is that the armature can turn faster, thus increasing speed. Rheostatic controls and shunts can still be found occasionally in DC motors with series connections in DC motors for trams. Vehicles with rheostatic control are not fitted with regenerative brakes. Rheostatic controls are just as wasteful when braking as they are during traction. The braking current is converted to heat via resistors and dissipated.

In order to able to continue using DC motors when upgrading vehicles, chopper control can give vehicles a completely new quality. With chopper control the field and armature of the motors are controlled separately. The chopper chops up the direct current into small pulses and feeds them directly to the field and/or armature of the DC motors. Lowering the exciting voltage results in higher revolutions and a drop in the armature voltage causes higher revolutions. This enables even, energy-efficient acceleration and braking.

The vehicle can now use the current it draws and the driver is responsible for an efficient current draw through his or her driving behaviour. By selecting the correct setpoint the driver determines how hard and how long the vehicle is accelerated or braked. The regenerative brake in chopper vehicles is an energy recovery brake. The unused braking energy is fed back into the traction grid to the busbar in the substation. In some vehicles the energy generated through braking is also used for heating on cold days, in addition to energy regeneration.

A further technical advance is represented by vehicles with three-phase asynchronous motors. The direct current is drawn from the overhead line and converted to alternating current via frequency converters and fed to the motor at

the corresponding frequencies. How much current is drawn from the overhead line or how high the control frequency is at the three-phase motor is determined, as always, by the driver, who sets the required acceleration on the setpoint device and hence the corresponding amount of current draw.

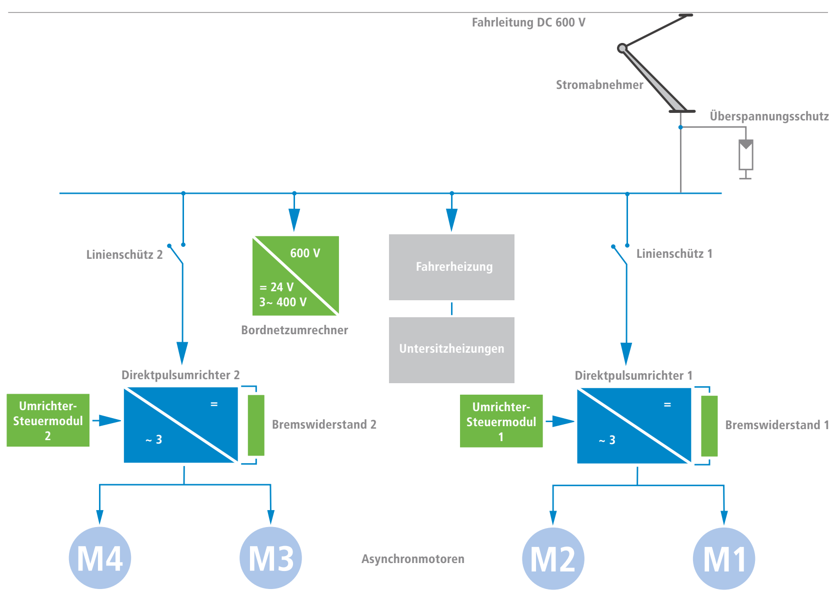
Irrespective of vehicle technology: the driving behaviour of the driver remains pivotal for possible energy savings. The higher the setting on the setpoint device, the higher the current draw and the faster the vehicle can accelerate. During braking the current to be fed back is rectified in the vehicle via rectifiers. Three-phase asynchronous motors are practically maintenance-free.

It is simply an induction machine, also called a squirrel cage. It is normally controlled by a direct pulse inverter (DPI). Slip and slide control is adjusted to a very fine setting. The vehicle software is adapted in an optimum manner to the vehicle and infrastructure of the pertinent city. Current is drawn in all trams via the pantograph.

As protection against a lightning strike, a lightning arrestor is installed immediately after the pantograph. The driver can even influence the 600 V auxiliary power circuits in the vehicle, at least to a certain extent.

The driver cannot influence consumption of the on-board converter but s/he can take a careful decision as to whether the air conditioning or heating must be switched on all the time in the passenger section. Control technology for trams is unthinkable nowadays without direct pulse inverters (DPIs) and IGBTs (insulated gate bipolar transistors). This type of technology is extremely accurate to ensure optimum current draw and energy recovery.

Bremsenergie wird in das Bahnstromnetz zurück gespeist.



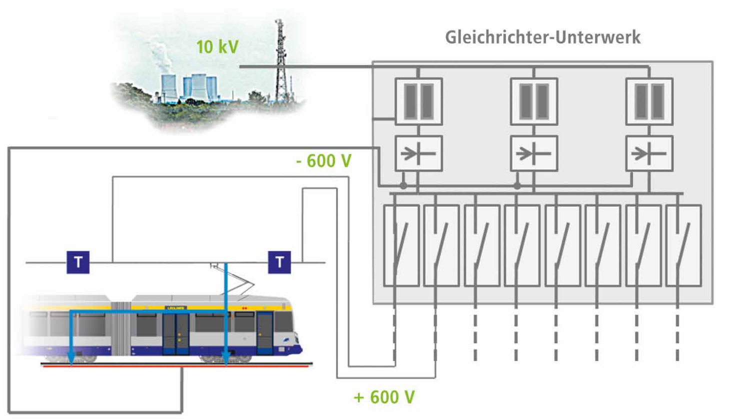
Der Fahrer gibt die gewünschte Beschleunigung und damit die Höhe der Stromaufnahme vor.

3.2 Energy supply

Energy is supplied via DC substations. The electricity arriving at the substation from the power plant is stepped down and rectified. This direct current is fed via track switches from a busbar into the traction grid where it can be used by vehicles.

If a vehicle feeds regen energy back into the grid, it is fed into the busbar and can be used on all lines connected to the busbar. In addition there is a connection via the rails where return cables are laid back to the substation. With the introduction of vehicles fitted with regenerative brakes into a company and decommissioning of vehicles using resistor control, overall electricity consumption will drop significantly through the modern technology alone.

But here we come back to the driver who can save even more energy through careful driving behaviour that also focusses on passengers' comfort.



3.3 Recording energy consumption

The best way to measure the energy consumption of individual drivers would be to install measuring devices in vehicles. It would be possible to record consumption constantly. The disadvantage of this method lies in the high costs, which not every company can afford.

Data protection laws in some countries are a further obstacle. In some countries there are statutory provisions that prohibit direct monitoring of the consumption readings for individual drivers or breaking down data to individual drivers. When planning to install measuring devices verify in advance whether statutory provisions or in-house rules (co-determination via the workers' council) allow this to be done.

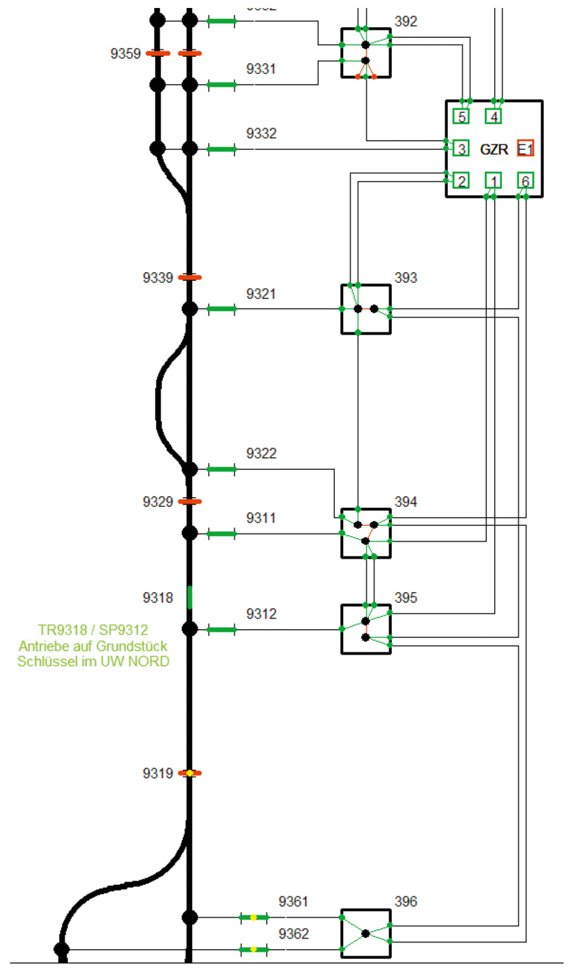
Another method, albeit a very costly and personnel intensive one, is to measure energy consumption via feeder stations in a substation.

The latest technology is only as good as the person using it.

But here, too, many companies are not allowed to match drivers' names to routes for reasons of data privacy, even though this would be theoretically possible.

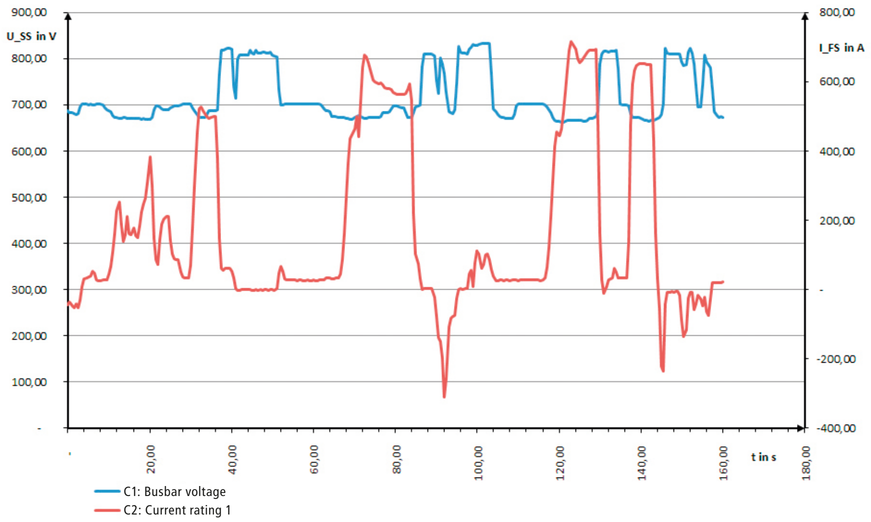
This method was applied in Leipzig, for example. Two measurements were taken in a substation supplying a single-track section, as well as other routes. The first measurement was taken at the beginning of the project with drivers who had not participated in training; the second was taken around six months later with trained drivers. On this section of track the energy readings of all trams were measured over one day. This required each individual journey to be measured manually at both measuring points (a circuit breaker at the start and end of the section) using triggers. 156 journeys were measured and subsequently evaluated. This single-track part of the measured section is c. 900 metres in length (photo right).

Using the resulting curves it was possible to draw conclusions regarding energy consumption during individual journeys. The following data was recorded: voltage and current rating, the type of vehicle and vehicle number, time and whether the journey was into town or out of town.



Auf der Messstrecke wurden Spannungen und Stromstärken aufgezeichnet.

3.4 Evaluation of results – using the Leipzig test



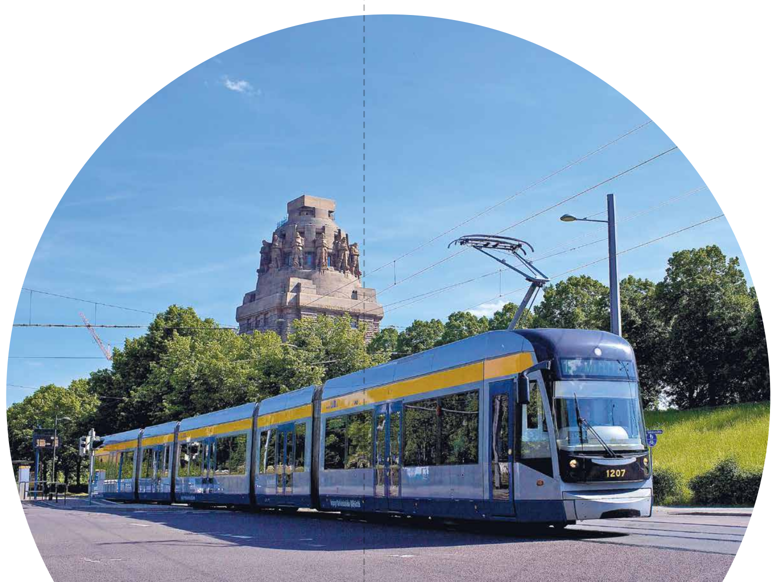
Zero = rolling

Actuation of the setpoint device by the driver can be seen in the graph by following the red curve. In this example it can be seen that there are too many uncontrolled acceleration phases and only very few rolling phases. The setpoint device was practically never at the zero point position. This gives the impression that the driver is "playing" with the setpoint device, constantly moving it backwards and forwards during the journey. In sections where the current rating (red) moves to the minus range, the driver is braking. If the current increases (blue curve) at the same time, the braking energy was being used by another vehicle at the same time.

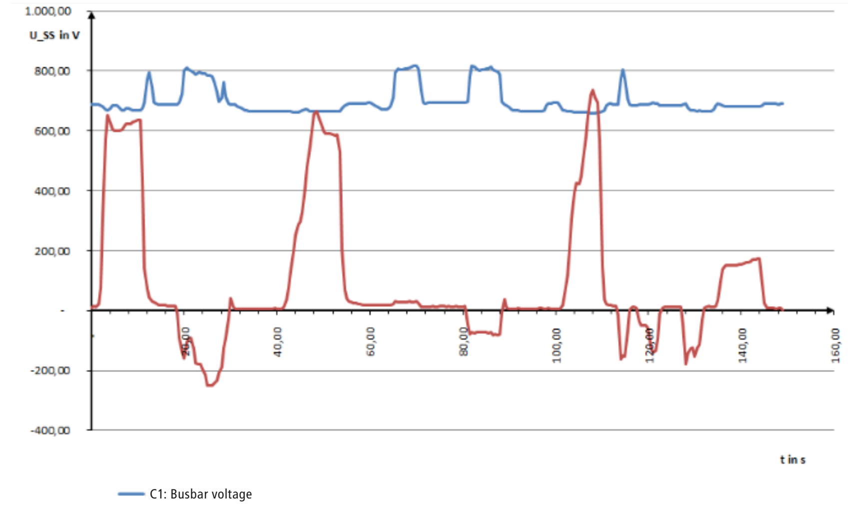
The conclusion to be drawn from this graph: **The driving behaviour of the driver on this graph is very uneconomical.** Energy consumption for this journey was 5.1 kWh/km.

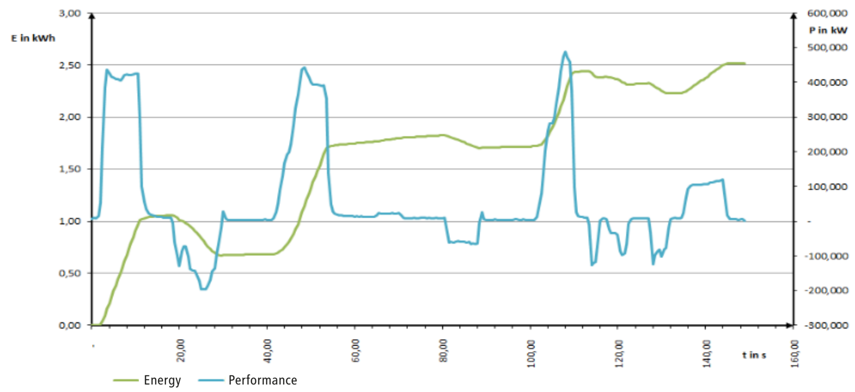
Following evaluation of the driving curves a statement can be formulated on ecodriving and calculations made to work out how much energy could be saved if all drivers complied with ecodriving rules. However, the costs of manual triggers are very high. The next example shows that it is possible to do things differently from the above graph.

With the same conditions as in the example above, a completely different graph was recorded. It is clear that acceleration and rolling used optimally.



Zero = rolling

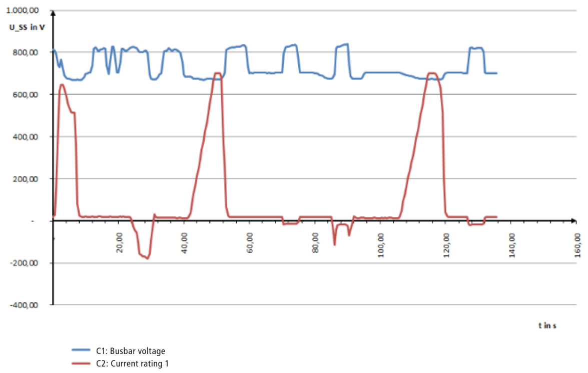




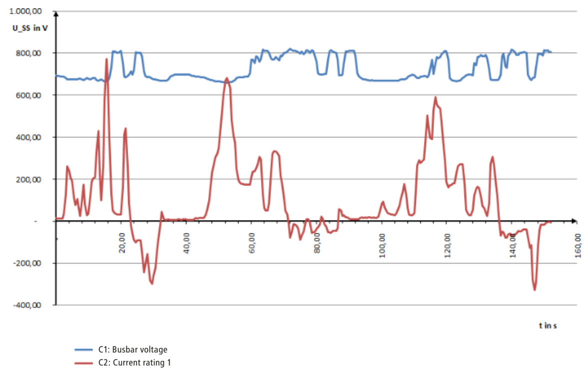
This time only 2.6 kWh/km were used (lower graph driving curve (blue) and energy consumption green line → on the left). This comparison shows how much energy saving potential there is. The municipal transport company of Leipzig has set itself a realistic goal of energy savings of 3 % through ecodriving.

The fleet of vehicles also plays an important role. Unfortunately it is often the case that the latest vehicles have the highest energy consumption. The air conditioning system for the passenger section clearly accounts for the greater part. Around 0.8 kWh are consumed by the air conditioning in the passenger section per measured journey. It would be possible technically to switch it off but this could not be put into practice because the passenger section does not have windows that open.

With regard to customer service, most passengers these days want air conditioning, therefore the transport company has to carefully consider the pros and cons.



Driving curve for the Tatra (pedal control)



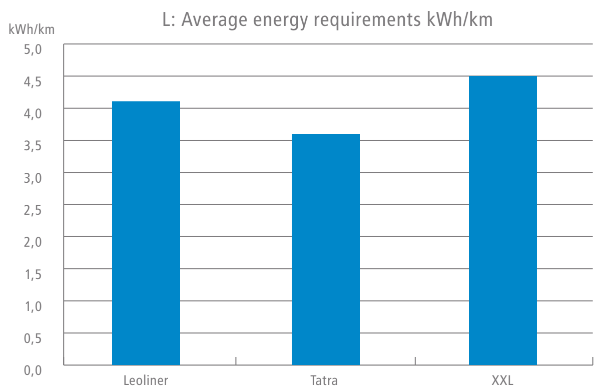
Driving curve for the NGT 12 (setpoint device)

In Leipzig a comparison of vehicle types revealed that the T4D-M with chopper control and foot pedal used the least energy. What is noticeable, or almost strange, are the two very different driving curves between the T4D-M (pedal control) and the vehicles using a setpoint device.

Most drivers displayed clean driving behaviour using traction and brake pedals. They accelerate and release the pedal when the speed is reached and allow the tram to roll. Sloppy driving behaviour with pedal controls was almost unknown.

However, it was noted that the driving behaviour of around 40 % of drivers in all vehicles fitted with hand controls (setpoint device) is simply "not optimal", which is, of course, in direct opposition to energy-saving driving behaviour. The driving curves show that the setpoint device (especially the very popular setpoint device XXL (NGT 12) induce many drivers to "play" with it without reflecting. The results from Leipzig show how important it is to prepare drivers to adopt energy saving driving behaviour.

The bar chart shows a comparison between 3 vehicles in Leipzig. T4D-M (Tatra) from CKD Prague (only pedal control, no air conditioning in the passenger section) upgraded with chopper control in 1994, Leoliner NGT 6 (no air conditioning in the passenger section) delivered by Heiterblick GmbH in 2006 and NGT 12 (with air conditioning in the passenger section) delivered by Bombardier in 2006.



Der Fahrgast nimmt eine vorausschauende und gleichmäßige Fahrt mit hohem Rollanteil positiv wahr.

We have to pay for the energy we need!

These results beg the following questions for drivers regarding ecodriving: should the re-introduction of pedal control be given serious thought? Can pedal control alone save energy? Siemens, for example, is building the "Avenio" with pedal control once more, at the express wish of some ordering parties from Belgium.

In order to achieve sustainability, the municipal transport company of Leipzig is offering its tram drivers practical training sessions during working hours.

As an aid to motivation, pens, notepads, a training brochure and a booklet with the most important guidelines on fault resolution for all types of vehicles are being handed out. Drivers are awarded a "green ecodriving licence" which entitles the bearer to participate in a tombola at the end of the year. At the end of each training session, drivers fill out a questionnaire on the relevant topic.

The "ACTUATE" project has been presented to other German driving schools for tram drivers. Tram driving instructors can complete training for multipliers offered over three workshops. Ecodriving should become a topic of conversation for the whole of Europe. Because energy has to be saved everywhere.

4 Malfunctions

Generalisations on vehicle malfunctions cannot be made due to the different systems used in the vehicle types available in Europe. Each city with a tram network has its own trams built specially for the city. Every tram is different and adapted to the wishes of the customer. Standardisation will not be possible in the tram sector. The individual needs of cities and their tram transport companies are too different.

However, when a malfunction occurs the following principle applies to all companies: Secure - Save - Report. If damage occurs to the overhead line, all dangling parts must always be treated as live parts. The location of the malfunction must be secured to prevent contact with these parts. Direct current is especially dangerous because you can stick to it and contact will be fatal if the source is not switched off immediately. Normally the track switches disengage immediately in the substation but if the overhead line has no earth contact it can still be live.

A person who touches it creates that earth contact. The track circuit will disengage then at the latest and turn off the power to that section. But it can be too late for that person. Therefore always take extreme care around electric currents. The current health & safety regulations of the relevant countries should be complied with and regular training provided.

Der Fahrer handelt nach dem Grundsatz: SICHERN RETTEN MELDEN

5 What role does a tram driving school play?

Tram driving schools are responsible in the individual countries for providing the best possible quality of training and advanced training for drivers with due consideration for all current statutory conditions.

Es gibt nur eins, was auf Dauer teurer ist als Bildung: keine Bildung!

John F. Kennedy

In order to offer a well prepared ecodriving training course, the initial focus must be on the existing fleet of vehicles. How well versed are drivers in the vehicles? How confident are drivers when dealing with faults? What is the current status (level of energy consumption) and what is actually to be achieved by the training course?

When defining the aim it is important to set a realistic goal, for example savings of 3 % in our Leipzig example. People must be clear about where savings can be made and a time must be set by which the goal must have been achieved. This goal must then be communicated accordingly.

The support of company management is needed here. Once the goal has been achieved, complacency should not be allowed to set in.

It is very important, albeit very difficult, to ensure the new skill of ecodriving is sustained. For example, an e-learning programme, a repeat training session or questions set as a postcard quiz can help.

Experience from the ACTUATE project has shown that small gifts, such as coffee mugs, a lunch box, a pen, etc. as a small thank-you and an aid to memory were met with very positive acceptance by the drivers of the companies participating in the project.

Education is the ability to be able to do almost everything without losing your calm and self-confidence

The success of the training course depends, of course, on a well-equipped driving school and competent driving instructors who are convinced of the usefulness of training and can act both as role models as well as figures of authority. The aim of a tram driving school should be to perform all commissioned tasks with the very best quality and to the highest standards.

This also means that all tram driving instructors must be very well trained and, where possible, should have completed a recognised form of training (foreman, trainer, technician). Their level of knowledge and methodology must be kept up to date through regular advanced training sessions.

Furthermore, a good training course depends on how well the instruction rooms are equipped, as well as on vehicles and measuring technology. Modern aids such as:

- laptop
- LCD projector
- whiteboard or blackboard
- pin board
- flip chart

should be available.

Moderne Technik in den Unterrichtsräumen: ***Beamer, Laptop Whiteboard, Flipchart, Pinnwand***

6 Ecodriving and timetables

The ecodriving behaviour described here must be imparted to the student during their driver training. However, once their training is completed, any factors contribute to drivers "forgetting" this way of driving.

The key word "timetable efficiency" is responsible for certain drivers forgetting all their good intentions. In order to make the timetable as efficient as possible in business terms, the intention is to offer as few routes as possible. But fewer routes mean fewer drivers. In order to achieve this, journey times and turning times at terminals must be kept as short as possible.

If slow sections, traffic jams and disruptions to the shift also occur, some drivers simply chase time without thinking. They rarely use rolling but switch instead between maximum acceleration and braking. But does ecodriving have such a negative impact on the timetable so that all good intentions have to be thrown overboard? No, because drivers do not drive more slowly, but more economically. However, in order to implement this type of driving behaviour it is necessary to think ahead when driving.

The driver must recognise whether it is worthwhile accelerating the vehicle or simply to let it roll. This is not always easy. A traffic jam in the rush hour cannot be made to disappear by waving a magic wand; however, the driver can try to drive the vehicle as smoothly as possible and to let it roll as long as possible in this type of situation. Ecodriving is also possible at low speed.

Of course, ecodriving should be supported with technical elements. It makes sense to set interaction with light signalling systems so that intersections can be crossed without having to stop. Installing a device in the tram which shows whether the driver is driving economically or not (similar to fuel consumption indicators in cars) can be a useful aid for drivers. There are also devices which indicate to the driver whether to accelerate or roll.

However, it is not always easy to balance all interests; ultimately each company must decide for itself what package of measures for training and compliance with ecodriving it wishes to introduce.

In der Ruhe liegt die Kraft!

7 Training

There are two ways of providing training on ecodriving. The first method is for all drivers in the driving school to be trained by the driving instructors themselves. Whether this is possible depends on the size of the company and the number of instructors as well as the training workload of the driving school. Again, each company must take this decision itself.

The second method is to select certain employees (for example, trainee drivers) who receive intensive and thorough training on this subject in the driving school with instruction on methodology. These well trained employees then act as multipliers and pass on their new knowledge to other drivers. The driving school must compile a training plan which includes vehicle fleet, topography, traffic conditions in the town and the general timetable or journey times (current timetable efficiency in the company). Therefore training can only be described in general terms.Training using multipliers is performed in two stages. The first stage is the theoretical training of multipliers in the driving school. This includes the subjects:

- Safety
- Vehicle dynamics
- Factors influencing vehicle dynamics
- Vehicle technology
- Energy supply
- Health & safety at work
- Fault resolution
- Driving behaviour and cost-effectiveness
- Teaching methods and tips for teaching others about driving behaviour

The practical part comprises driving practice in the tram form the point of view of ecodriving, supervised and guided by the driving instructor, i.e. application of the theory learned (repeated) in practice. The driving instructor must provide systematic instructions. On completing this training, the multipliers train other drivers by accompanying them on routes. This should last for one or two complete circuits of the route (depending on the length of the route). Subsequently some "golden rules" can be provided on ecodriving.

These can take the form of a small booklet, with the rules printed on the cover and instructions for fault resolution applicable to the existing vehicle fleet included inside the booklet. In order to motivate drivers and multipliers, a type of ranking could be introduced between teams of drivers, for example, who are assigned one or two multipliers. The best group of the month and its multipliers will receive a small token of recognition because multiplier training will not achieve the desired success without any motivators.

The golden rules:

1. **Accelerate vehicles slowly and evenly**
2. **Consider adhesion when accelerating**
3. **When the required speed is reached go to neutral and allow the vehicle to roll**
4. **Always think ahead when driving**
5. **Start to apply the brakes in good time**
6. **Brake evenly**

In order to get the subject of ecodriving firmly and permanently fixed in drivers' minds, they must be reminded again and again of the importance of saving energy. This can be done, for example, in a short practical training session for drivers in the following year. The drivers take part in training sessions of 3 hours each spread over the whole year as a practical review carried out by the driving school. This means the results of ecodriving can be checked once more in a group of 4-5 participants.

The effects on energy consumption must also be repeated during on-the-job training:

- Driving style
- Anticipatory driving behaviour
- Vehicle maintenance and support
- Traffic volume
- Topography
- Condition of tracks
- Vehicle type
- Passenger volume
- Motivation

8 Summary

Saving energy has become an important subject throughout Europe. Many cities and tram manufacturers are spending a lot of money on research and development of energy saving measures and renewable energies. But this is a worthwhile investment because it is an investment in the future, which we will all benefit from. Because saving energy means saving money and it protects the environment.

And, similar to transport companies, we can also save energy at home. Are you using eco-friendly domestic appliances? Do you always switch off the light when you leave a room? Is your TV always on, even if you're not watching it? Test yourself!

Excerpt from news and press on the web:
Quote: Vienna, Thursday 10 July 2014
Media contact: Veronika Gasser

„More than 13 per cent energy savings
Ecotram research project comes to successful end

The energy saving tram of Wiener Linien was running on line 62 until May as part of the "Ecotram" research project, with the aim of identifying possible energy savings in the heating, ventilation and air conditioning systems in low-floor trams. Over the past 10 months the Ecotram was able to record valuable data over on energy consumption for passenger services. The Ecotram saved around 4,200 kilowatt hours or more than 13 per cent energy for heating, ventilation and air conditioning during this period. This is the equivalent of the annual energy consumption of an average household in Austria."

This article from a Viennese newspaper is intended to illustrate how important this subject is for all of us and that each one of us has a contribution to make to save energy and conserve resources. We must be careful in using energy and we should not tolerate waste. The journey from energy generation to the consumer is a long one.

The potential offered for saving energy through ecodriving of trams is illustrated, for example, by the results of energy measurements taken in Leipzig. Every single company that intends to save energy with well-trained drivers can utilise this training booklet, adapt it to the relevant city or local conditions and put the training concept into practice.

This training booklet, developed under the direction of Leipzig's project partners in the ACTUATE project, will help you to start to tackle the subject of saving energy through ecodriving in your company.

We wish you every success!

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The ACTUATE consortium:

The ACTUATE consortium consists of five advanced European public transport operators from Salzburg (Salzburg AG, Austria), Brno (DPMB, Czech Republic), Parma (TEP S.p.A, Italy), Leipzig (LVB, Germany), and Eberswalde (BBG, Germany) who already operate electric vehicles, as well as LAB bus driving school in Leipzig, the Belgian bus manufacturer Van Hool and trolley:motion, the international action group to promote e-bus systems with zero emission (Austria). The project is coordinated by Rupprecht Consult GmbH (Germany).

Education is
the ability to be able
to do almost
everything without
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