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DUAL LOCOMOTIVES FOR REGIONAL FREIGHT TRAINS

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Abstract

This paper focuses on the possibilities of using dual locomotives in freight rail transport. It presents different types of power supplies for these vehicles, their categories and shows the possibilities of use regarding operational efficiency and emission savings. On a practical example, it demonstrates the suitability of deploying dual locomotives for a wide range of operation, including considerable savings in traction energy costs. It also provides examples of real deployment of these machines, particularly in the Czech Republic and the Central European region in general. Finally, an assessment of the benefits of dual engines is presented and a recommendation for appropriate operational deployment is made.

Keywords: dual locomotive, freight transport, hybrid locomotive, last-mile, passenger transport

1 Introduction

Historically, all railway traction vehicles had only one mode of propulsion. However, the development of operational and technical circumstances over time led their designers to the idea of fitting several power units into one vehicle, which can replace or complement each other, or serve specific purposes. Such vehicles came to be known as dual-source, dual or hybrid vehicles.
At present, these vehicles provide only a small percentage of the performance on the European railway network, although their potential is certainly not negligible thanks to the rapid development of appropriate technologies. The aim of this article is to present them in a more detailed way and formulate recommendations for their deployment for suitable performance.

2 Categorization of dual locomotives

A dual-source vehicle can generally be considered as a railway traction vehicle having more than one (usually two) power sources. Typically, there is one primary and one secondary power source, intended for use only in enumerated operating situations and under specific conditions. The reasons for using a secondary energy source can be various, whether operational, technical (e.g., absence of overhead contact line or feeder rail) or economic (lower power or lower unit cost of energy, and thus lower operating costs). With few exceptions, a traction vehicle cannot be operated on both energy sources at the same time – it must be clearly time-framed, when the vehicle is powered by one or the other energy source.
Therefore, in most cases, the secondary power source cannot fully replace the primary power source and only serves as a substitute in cases where it cannot be used for the reasons mentioned above. In exceptional cases, it can act as a substitute for the primary power source if it fails. The vehicle is usually limited in secondary power mode both in speed and traction

power, and the range in this mode is also limited. The duration of operation from secondary power source can be in the order of a few seconds (e.g., for locomotives with feeder rail power) to tens of minutes (electric locomotives with auxiliary internal combustion engine). Partial (or hybrid, dual) electric vehicles are generally defined as electric vehicles capable of operating in both traction modes (dependent and independent on the catenary). These are generally electric vehicles that can be fully operated on sections without a catenary, either using a diesel engine or batteries. In urban public transport, partial trolleybuses equipped with auxiliary batteries are thus becoming widespread, enabling them to serve even the end sections of lines lacking catenary where there is insufficient passenger demand for transport. On the railway are already in operation dual-source electric traction units (BEMU) and dual locomotives, which will be described in a more detailed way below [1].

3 Types of dual locomotives and a brief history

Although the first dual-source vehicles were developed abroad before the Second World War, in former Czechoslovakia the replacement of conventional diesel-electric locomotives began to be addressed only in the 1980s, in connection with the rising prices of traction energy (mainly due to the rising price of oil and therefore diesel fuel). Several historical examples can thus be used to present a range of possible conceptual arrangements for dual-source vehicles.

3.1 Electric locomotive with a diesel locomotive

In the short-distance service, a combination of an electric locomotive and a smaller diesel locomotive is possible to use for pulling freight trains on electrified lines instead of the traditional diesel locomotive, which works and consumes diesel under catenary most of the time. Although this is not a dual-source vehicle in the true sense of the word, it is one of the possible solutions that enables cost saving. The idea is to run the train with an electric locomotive (of sufficient power) on the electrified sections of the line, while the work of the auxiliary diesel locomotive can be the handling of wagons in the stations, the operation of sidings and possible operation on non-electrified side lines. Although there will be an increase of number of locomotives required and longer stays in stations (requiring the driver to switch between the two vehicles), the savings in traction energy can be significant and the reduction in emissions is also an undeniable benefit, typically in areas with persistently poor air quality.

Figure 1 Electric loco class 230 together with diesel loco class 731 pulling a short freight train

3.2 Diesel-battery locomotive

An analysis of the operation of shunting locomotives in various stations showed that up to 2/3 of their operating time is spent by idling their average power for the whole operating time does not exceed 10 % of the rated power and they do not need the rated power for more than 2 % of the total service time [2]. It is clear from these conclusions that conventional diesel-electric locomotives do not operate economically in this mode and their operation is made more expensive by the large amount of fuel burnt at idle speed. Considerable emissions are also an important factor. Therefore, another possible alternative is to produce a locomotive with a small diesel engine (low idling consumption), ensuring the locomotive's continuous availability, and supplemented by a traction battery in the event of a short-term need for high traction power. This battery can be recharged directly from the diesel engine driving the power generator during breaks in service, or the regenerative brakes can be used during service braking, returning otherwise wasted kinetic energy back to the battery.

3.3 Electric locomotive with a battery wagon

In the early 90s, Czech state railways were looking for some solution, which should reduce fuel consumption in the short-distance freight trains service, and in České Budějovice depot, the workers came with a possibility of using a conventional electric loco with batteries, which should be put into a freight wagon and coupled by cables with the loco. Total 5 locos of class 210 were modified and used in freight trains service on lines in Southern Bohemia.
Although the use of a battery wagon was the simplest and seemingly cheapest solution at the time, it brought considerable complications in operation, especially during shunting – the wagon had to be detoured when reaching the final station, it worsened the driver's view, in battery mode the compressor was not powered and therefore it was not possible to refill the air sumps. Finally, in today's context it would also increase the fee that the operator must pay to the infrastructure manager for the use of the track. It is also necessary to mention the very limited power of the batteries (the solution, mentioned above, has approximately 100 kW maximum power), which allows only a limited amount of load to be transported and at low speeds [3]. The lifetime of the batteries is in the range of 5-15 years (depending on the using strategy) [3].

3.4 Electric locomotive with auxiliary diesel engine

The development of technology in the last decade has also brought the creation of several full-fledged electric locomotives, equipped with a small diesel engine of significantly lower power, designed for shunting, operating sidings, or riding with the train in the so-called last mile mode. This is particularly aimed at saving costs in situations where the train's starting or end station is outside the catenary, but the gradient conditions do not require the use of a high-power locomotive to reach this point. Thus, the train can be run along the entire route (even across several countries) by a single locomotive that switches to diesel engine operation during the journey and traverse the necessary sections in this way. At the same time, it is a solution that allows the train to move in an emergency in the event of a power failure of the overhead line (in places where the gradient conditions allow it, given the low power of the diesel engine). Several manufacturers have undertaken the development and production of these locomotives in Europe, among which three main ones stand out – Bombardier (now part of the Alstom concern), Pesa and Siemens.
In 2011, Bombardier introduced a locomotive from its TRAXX family equipped with a 230-kW auxiliary diesel engine from Deutz. In electric mode (15 kV 16.7 Hz and 25 kV 50 Hz AC systems), the locomotive has a continuous power output of 5,600 kW. The locomotive, named

AC3 F140 Last-mile, has been ordered by the German operator Railpool and several other entities. It received permission to operate on the German, Austrian and Swiss rail networks in early 2016 [4].

Figure 2 Siemens Vectron AC, equipped with last-mile module (diesel engine), with freight train outside of the electrified track

A similar locomotive was introduced a year earlier (in 2010) by Siemens, based on its Vectron platform. The 180-kW diesel engine is manufactured by Steyr and can be fitted to Vectron AC (for AC traction systems) or Vectron DC (for 3 kV DC traction systems) locomotives as an optional accessory from the factory or at any time during operation. The first such locomotive was ordered in 2017 by the Italian company InRail (variant DC), followed by other operators, such as Hungarian company GySEV. The advantage of these locomotives is their high tractive force thanks to the drive of all wheelsets, and therefore they are able, albeit at low speed (which does not matter during shunting), to haul a heavy train from (or to) a non-electrified siding. This often replaces the inefficient running of a diesel locomotive even hundreds of kilometres under traction [5].

Polish manufacturer Pesa Bydgoszcz offers such a product under the 111Ed "Marathon" designation. It is a locomotive from the Gama family, introduced in 2012. In electric mode, it has similar parameters to the products of the two previous companies (power 5,600 kW), but for off-line operation, a Caterpillar diesel engine with significantly higher output (403 kW) is fitted. However, unlike the TRAXX and Vectron platforms, only the 3 kV DC version is offered, and the locomotive is only approved for use on lines in Poland.

3.5 Full dual locomotive

The last type of dual-source vehicle that will be introduced in this paper is the dual vehicle in the truest sense of the word. Dual vehicles achieve significantly higher performance in independent traction mode of operation than vehicles with an auxiliary internal combustion engine, and this mode is certainly not considered as an emergency or shunting mode. However, compared to traditional electric locomotives, they logically have a lower specific traction power due to the incorporation of a large diesel engine and its accessories. They can be designed as power-symmetrical (i.e., they have the same traction characteristics on electrified and non-electrified lines, but on electrified lines they take advantage of the linear electric power supply, the diesel engine is a full power source), or as power-asymmetrical (on non-electrified lines they have lower power than on electrified lines, the diesel engine is a supplementary power source). Some renowned manufacturers already offer these vehicles in their production programmes; in addition to the Siemens, the Spanish subsidiary Stadler Rail Valencia with its Euro Dual product. Their parameters are summarised in the following table:

Table 1 Dual locomotives by Siemens and Stadler

Manufacturer	Siemens	Stadler
Name	Vectron Dual Mode	Euro Dual
Number of axles	4	6
Output in E mode	2,400 kW	7,000 kW
Output v D mode	2,400 kW	up to 2,800 kW[1]
Top speed	160 km/h	160 km/h
[1] depending on used diesel engine		

The significantly higher performance of the Stadler vehicle is mainly due to the longer frame and the six-axle design; the Euro Dual is designed especially for heavy freight transport. In contrast, Siemens' product, the Vectron Dual Mode, is designed as a vehicle with equivalent traction characteristics in both dependent and independent traction modes, and for universal use in passenger and freight transport. These locomotives are already in use mainly in Germany (10 Euro Dual machines are operated by Havelländische Eisenbahnen, and another 10 are owned by European Loc Pool) and Austria. However, their operation is gradually expanding in other European countries as well [6].
Dual locomotives are also used in Canada, represented by the type called ALP-45DP from Bombardier. Total 80 locomotives were delivered to Montreal, where are used mainly for passenger service [7]. Same locomotives were bought also by New Jersey Transit in the USA.

4 Dual locomotives and their suitability for regional freight trains

Large amounts of diesel fuel are consumed by diesel locomotives (and produce associated emissions) under catenary. These are mainly local freight trains on electrified lines and train shunting on electrified stations. In these activities, diesel locomotives are almost always under the catenary, which they do not use. In this deployment they only occasionally go onto non-electrified handling tracks, sidings, or sidings where they need diesel power independent of the overhead line. They then use the diesel drive inefficiently under the overhead line, which is accompanied by its low efficiency and lack of regenerative braking. In order to reduce energy and maintenance costs, to reduce emissions of carbon dioxide and health-harming substances, and to substantially reduce noise at stations, Deutsche Bahn (DB) has decided to replace the ageing four-axle class 290/291 diesel locomotives (809 kW, 79 t, 80 km/h) not with diesel locomotives again, but with the class 248 electric/diesel dual-source locomotives.
In contrast to the above-mentioned power-symmetrical Vectron DM locomotives, these locomotives are designed as power-asymmetrical. The reason for this is the desire to transport also handling freight trains between stations on heavily congested lines quickly and not to block the capacity of the railway lines or to delay the service of railway stations by long waiting for a free slower time slot. However, a less powerful diesel engine with a lower basic (idling) fuel consumption is sufficient for station shunting.
These are transport outputs that are expected to grow significantly in line with the Green Deal objectives (shifting freight from road to rail) – railway needs to serve a wide network of loading and unloading points in addition to providing long-distance transport. By carrying out analyses, DB has determined the total need for new dual four-axle locomotives to be 400. Following a competitive tender, Siemens Mobility was awarded the contract and offered a solution based on the Vectron Dual Mode platform, tailored to the required operating conditions. In September 2020, a contract was concluded for the delivery of the first 100 locomotives with an option for a further 100. In January 2022, DB ordered 46 locomotives of this option type and Bahnbau operator ordered 4 locomotives.

According to its calculations, DB expects to save 220 litres of diesel per locomotive per day, or 80,000 litres per locomotive per year. The traction power of the new four-axle dual class 248 locomotives is up to 2,200 kW with an electrical supply of 15 kV 16.7 Hz.
This significant increase in power compared to the existing class 290/291 diesel locomotives will enable the speed of freight trains carried by them to be increased on heavily congested electrified mainlines. Faster running in conjunction with other trains is a condition for obtaining a free time slot without long waiting for off-peak time [8]. This is very serious problem to discuss because the poor dynamics are one of the most limiting parameters of short-distance freight trains, usually pulled by diesel locomotives.
Also, the permanent power of the diesel engine is somewhat increased compared to the original diesel locomotives to 950 kW. In both modes (electric and diesel), the new locomotives will have a maximum starting tractive effort of 300 kN and a top operating speed of 120 km/h. The locomotives will also be equipped with train protection devices (PZB/LZB and ETCS) corresponding to the conditions of operation on the main lines. They can also be used to transport heavier trains in multiple-unit control regime, both with locomotives of the same design (DM) and in combination with purely electric Vectron locomotives (class 193).
A distinctive feature of the new dual locomotives is the front walkways with railings and spacious side steps with handrails. This solution, together with automatic couplings for shunting, enables remote control of the locomotive by a command radio station. Ambient lighting, specifically directed cameras, a system of voice radio communication and other elements create the conditions for targeted application of modern technologies in shunting, which is part of the operation of regional freight trains.

5 Comparison of dual and diesel locomotive deployment

As described above, diesel-electric locomotives are still deployed on a significant number of trains running on electrified lines throughout the route (or most of it). It is worth recalling that in 2019, on the Czech railway network:
- 95.5 % of freight trains were operating on electrified lines,
- 86.8 % of transport capacity of freight railway transport were operated by electric locomotives.

Diesel locomotives provide almost twice as much traffic on electrified lines (8.7 %) than on non-electrified lines (4.5 %). This a serious topic to address [9]. The aim of this part of the text is, on the basis of comparative calculations, to quantify the energy consumption and the resulting savings when running a train with a two-source locomotive, in different variants (both with auxiliary diesel generator and traction batteries). [10]
In the examples, the comparison of traction energy consumption and costs for four variants is addressed, where a) and b) are comparative variants:
a) Conventional diesel-electric locomotive (for example Czech class 742)
b) Electric locomotive, counting with a theory, that all tracks are electrified (for example Czech class 210)
c) Dual locomotive with auxiliary diesel engine (class 210 D)
d) Partial dual locomotive with traction battery (class 210 A)

To calculate the energy consumption, a calculation is used using a simple model, working with the methodology of physical resistances of the environment, expressed as a proportion of the gravitational force acting on the train.

The most important such components are:
• Specific traction resistivity
• Mean specific curve resistivity
• Mean acceleration resistivity

The sum of all these specific resistivities is called the mean specific traction resistivity. In order to determine the values of each of these resistivities, it is necessary to know a number of physical quantities and values, which depend not only on the specific type and parameters of the vehicle, but also on the parameters of the track and the surrounding environment. All resistivities are treated as dimensionless quantities with the unit N/kN [8].

a) Specific traction resistivity
The first component is the specific driving resistivity p_0, which is based mainly on train's movement. Its value is

$$p_0 = a + c \cdot v^2 \left[\frac{N}{kN}\right] \tag{1}$$

where a is specific rolling resistivity, c specific aerodynamic drag and v the speed of the train (vehicle). All variables are defined as constant, i.e. their values do not change with time. The values given are valid for freight trains with different types of wagons braked by cast iron blocks.

Table 2 Defined values of aerodynamic drag coefficient

Parameter	Mark	Value	Unit
Specific rolling resistivity	a	1.3	N/kN
Specific aerodynamic drag coefficient	c	0.0003	$N/kN/(km/h)^2$

b) Mean specific curve resistivity
The second component of the specific traction resistance p_r is the mean specific resistance from the curve, which depends mainly on the directional parameters of the line or line section. The Röckel's formula is used:

$$p_r = \frac{650}{R-50} \cdot \frac{k}{100} \left[\frac{N}{kN}\right] \tag{2}$$

where R is average radius of curve on the track and k the percentage of the length of the curves on the total length of the track. The value 650 is taken for main lines (in the case of secondary lines it can be replaced by 500 and 30; however, the example is from a main line.

c) Mean acceleration resistivity
The last component, reflected in the calculation of the specific traction resistance, is the acceleration resistivity (p_a). Its value is based primarily on the nature of the journey, i.e. the speed of the train and the frequency of stops. Its value is

$$p_a = \frac{0{,}5 \cdot \xi \cdot v^2}{3{,}6^2 \cdot g \cdot L} \left[\frac{N}{kN}\right] \tag{3}$$

where ξ is rotating mass coefficient, v is the speed after finishing acceleration (it's calculated with 95 % of maximum allowed / operational speed), g is the gravitational acceleration and L average distance between train stops. Value ξ = 1.06 is set as constant.

The total value of the driving resistance is therefore calculated as

$$\sum p = p_o + p_r + p_a + s \left[\frac{N}{kN}\right] \tag{4}$$

where p_0, p_r a p_a are the specific resistivities and s is the average gradient on the line (in ‰). After the determination of the driving resistance for the line and the specific power, the specific traction work is calculated, which allows the conversion of the driving resistance into units suitable for the conversion of the consumed energy into the total transport power. This is calculated in standard units, i.e. tonne-kilometres (tkm). Formula for calculating the total transport performance:

$$W = w \cdot m \cdot L \left[\frac{kWh}{1000\ tkm}\right] \tag{5}$$

where w is the total transport work, m is the train weight (total weight – locomotive + wagons together) and L the distance over which the train weight is moved. Formula for calculating the specific traction work:

$$w_t = \frac{g \cdot \sum p}{3{,}6} \left[\frac{kWh}{1000\ tkm}\right] \tag{6}$$

The calculated traction work is already the basis for determining the specific work of the drive itself and the resulting specific energy consumption for the given transport performance.
The last of the preparatory calculations is the calculation of specific energy consumption. The already calculated specific traction work and the efficiency of the energy source are used to determine it. This is defined by constants:

Table 3 Defined efficiency values

Parameter	Mark	Value	Unit
Calorific value of diesel	H	10	kWh/l
Efficiency of primary traction source	n_p	97	%
Efficiency of electric traction in dependent traction	n_e	85	%
Efficiency of electric traction in independent traction (battery)	n_a	74	%

The result is therefore the specific traction energy consumption according to the formula

$$q_D = \frac{w_t}{H} \left[\frac{liter}{1000\ tkm}\right] \tag{7}$$

for diesel traction and

$$q_E = \frac{w_t}{n} \left[\frac{kWh}{1000\ tkm}\right] \tag{8}$$

for electric traction, where w_t is specific traction work, H calorific value of diesel and n efficiency. The value of specific traction energy obtained in this way can be used in the calculation of the total energy consumption at the selected power output.

6 Calculation of transport work and total consumption

The calculation of the actual transport work on a given performance is based on the train load and the distance the train travels on its route. The total transport work is quantified in tonne-kilometres. The train load and its progress are defined in detail in each example separately. The transport work (D) is determined by the formula

$$D = m \cdot L \tag{9}$$

which is based on the calculation of the total transport performance solved above. The total energy consumption of the subject power is therefore expressed by the formula

$$Q = q \cdot D \tag{10}$$

where q is specific traction energy consumption and D is total transport work. The resulting consumption can then be used to compare the energy consumption of each type of vehicle and quantify its costs if necessary.

Example

The regional freight train Vranovice – Břeclav – Moravský Písek was selected as one of the most suitable performances for the operation of a two-source locomotive at present. This train runs along the entire route on a double-track electrified corridor-type line with a 25 Kv/50 Hz AC power supply system; its locomotive runs off the catenary only when serving the secondary tracks and sidings at the siding stations. At present, a conventional diesel locomotive class 742 (with power output 800 Kw) is used on this train.
In this example, for simplicity, the model of simple wagons is used, where all wagons are considered as strictly uniform: the weight of each empty wagon is 25 tonnes, the weight of a loaded wagon is 75 tonnes. An overview of train weights based on long-term monitoring by the author is given in the tables 4 and 5.
The load is considered the same in both directions. The train handles the wagons at all the stations listed along the way. The line, with a total length of 72 km, runs in a flat landscape with minimal longitudinal gradients – the highest gradient along the entire route is 4.7 ‰, the average radius of the curve is more than 1 000 m. The dual locomotive runs on electric power in the intermediate sections and uses a diesel engine or a battery for shunting.

Table 4 Train weight in direction Vranovice – Moravský Písek

Track section	**Composition of the train (wagons)**	**Total weight** [t]
Vranovice – Šakvice	4 loaded	300
Šakvice – Zaječí	4 loaded + 2 empty	350
Zaječí – Břeclav	7 loaded + 6 empty	675
Břeclav – Lužice	3 loaded + 10 empty	475
Lužice – Hodonín	3 loaded + 7 empty	400
Hodonín – Rohatec	3 loaded + 4 empty	325
Rohatec – Bzenec přívoz	3 loaded + 2 empty	275
Bzenec přívoz – Mor. Písek	3 loaded	225

Table 5 Train weight in direction Moravský Písek – Vranovice

Track section	Composition of the train (wagons)	Total weight [t]
Mor. Písek – Bzenec přívoz	3 empty	75
Bzenec přívoz – Rohatec	2 loaded + 3 empty	225
Rohatec – Hodonín	4 loaded + 3 empty	375
Hodonín – Lužice	7 loaded + 3 empty	600
Lužice – Břeclav	10 loaded + 3 empty	825
Břeclav – Zaječí	6 loaded + 7 empty	625
Zaječí – Šakvice	2 loaded + 4 empty	250
Šakvice – Vranovice	4 empty	100

7 Results

For the equivalent comparison of all types of locomotives, their energy consumption and operating costs, the weighted sum method was chosen, where the total traction energy consists of:

- for a diesel loco class 742 only the diesel consumption, converted by the calorific value of diesel
- for an electric loco class 210 only the consumption of electricity
- for a hybrid loco class 210 D the consumption of electricity, added up with a diesel consumption of the auxiliary diesel engine and converted by the calorific value of diesel
- for a dual loco class 210 A the consumption of electricity, added up with a consumption of electricity when running on battery power

Total amount of energy consumed Q is based on the formula

$$Q = q_D + q_E + q_A \quad [\text{kWh}] \tag{11}$$

q_D, q_E and q_A are specific traction energy consumptions for every traction mode (diesel, electric, battery). The energy consumption thus expressed is then converted into operating costs P by multiplying the prices of the respective energy sources, i.e.

$$P = \frac{q_D}{H} \cdot P_D + \left(q_E + q_A\right) \cdot P_E \quad [\text{Kč}] \tag{12}$$

where H is the calorific value of diesel, P_D is the price of diesel, and P_E is the price of electricity according to the table 3 above. Total operating costs of all types of locomotives are illustrated by table 6.

Using the example chosen, it is clear that by deploying a locomotive using electric traction for a substantial part of the route, it is possible to reduce the cost of traction energy by up to approximately 75 percent. This significant difference is mainly due to the high diesel consumption of the diesel locomotive due to the significantly lower efficiency of diesel engine. If the locomotive is used efficiently at least every working day (250 days per year), the savings in traction energy costs amount to approximately CZK 4 million per year (ca. 170,000 €). It is worth to note that the way in which the locomotive is powered off the overhead contact line (E, D, A) has no significant effect on the total cost.

Table 6 Operational costs of all types of locomotives on the line Vranovice – Moravský Písek

loco	VR-BV		BV-MP		MP-BV		BV-VR		Total	
	Q [kWh]	[CZK]	Q [kWh]	[CZK]	Q [kWh]	[CZK]	Q [kWh]	[CZK]	Q [kWh]	[CZK]
742	1,748	4,894	1,720	4,816	2,083	5,833	1,464	4,101	7,016	19,644
210 E	643	1,480	601	1,382	756	1,738	538	1,237	2,538	5,836
210 D	560	1,316	535	1,273	668	1,586	472	1,116	2,235	5,291
210 A	532	1,223	485	1,115	617	1,420	441	1,014	2,075	4,772

It is essential that diesel engine is not used on the electrified lines, as the most energy is consumed when running between stations. However, the calculation does not include the cost of potentially more complex and expensive maintenance of the dual-engine vehicle, staff training and other expenses. It is therefore up to each operator to decide whether the acquisition and operation of such a vehicle is not only economically but also environmentally beneficial [11].

8 Selected other options for deployment of dual locomotives

Of course, one comparative example presented cannot cover all aspects of the operation of these vehicles. In general, however, it can be stated that dual-source vehicles can be deployed for a wide range of performances with respect to the setting of their performance levels, both in freight and passenger transport.

In passenger transport, for example, it is possible to consider the deployment of dual locomotives on routes, where part of the train route runs on electrified lines and part on non-electrified lines. Typical example is the EuroCity train from Prague to Munich, where the parts Prague – Plzeň and Schwandorf – Munich are electrified, while the middle section between Plzeň and Schwandorf not. The present situation is to change a locomotive twice, but dual locomotive (with a driving wagon) allows to pull the train on whole route and shorten the total travel time. Similar examples can be found all around Europe.

In freight transport, the spectrum of possible deployment is even wider. Dual locomotives can be deployed for operation similar to those mentioned above in passenger transport. Electric locomotives with auxiliary diesel engine are particularly suitable for deployment on trains where the origin/destination station is near the electrified line and the gradient conditions do not require high power outside the catenary. Such a locomotive can also lift a train from a siding yard or similar locations, for example car factories, coal mines etc., instead of a conventional diesel locomotive [12].

Dual shunting locomotives of different power categories can then replace conventional diesel locomotives at shunting yards and local freight trains, like the example mentioned above. One of practical examples is the locomotive of class Eem 923 (built by Stadler), which is already being successfully used in Switzerland for such applications. [13] The main benefit of using these high-performance dual locos is shortening travel times, as well as reduction of emissions. The travel time is directly proportional to the vehicle's output (class Eem 923: 1 500 kW in electric mode, conventional diesel locomotive: ca. 700 – 800 kW) [14]. Using diesel locomotives, or combinations of diesel and electric locomotives, is less effective in this case, because of poor dynamics and longer shunting times (e.g., when changing from one loco to another).

In bigger stations, affected by a huge number of transiting trains, according to a qualified estimation, using these high-performance dual locos should decrease the time, required to stay in the station, up to 50 – 70 %. For example, in some stations in Czechia, are now transiting passenger trains stopping for 10 – 15 minutes. When pulled by dual locomotive, this time could be shortened to 3 – 5 minutes and the shunting work is reduced to zero [14].

9 Evaluation

Thanks to rapid development of technology and the active approach of many manufacturers to it, the range of dual-source vehicles on the market has expanded considerably in recent years and the parameters of the products offered have improved significantly. Their main advantages are quieter and more dynamic operation, reducing emissions and noise, as well as labour savings. When deployed at the appropriate capacity, very significant energy savings can be achieved with a dual-source vehicle and at the same time further benefits can be obtained, like mentioned above. Electric locomotives with an internal combustion engine save operators the costs affected by having a second (diesel) locomotive to cover short sections (so-called "last mile"). Twin-engine vehicles can therefore replace in many places the inadequate vehicles that have been deployed so far for the work in question because of the lack of other suitable vehicles. However, the specific quantification of savings is always largely dependent on the nature of the performance to be deployed (how much of the service is performed under catenary).

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