LOGI – Scientific Journal on Transport and Logistics
Vol. 16 No. 1 2025 DOI: 10.2478/logi-2025-0020

Modernization of Railway Vehicles and its Impact on the Carrier's Operating Costs in Regional Railway Transport

Jaroslav Matuška[1*] and Josef Zitko[2]

[1]*University of Pardubice, Department of Transport Technology and Control, Studentská 95, 53210 Pardubice, Czech Republic; Email: jaroslav.matuska@upce.cz*
[2]*Správa železnic, s.o., Dlážděná 1003/7, 11000 Praha 1, Czech Republic; Email: zitko@spravazeleznic.cz*

***Corresponding Author:** Jaroslav Matuška

Received: 25 March 2025; Revised: 10 December 2025; Accepted: 17 December 2025; Published: 23 December 2025

Abstract: In a period of economic turbulence and rising input costs such as labour, fuel, and traction energy, railway operators face increasing operating expenses. The authors focus on the modernization of regional railway vehicles and assess its impact on operating costs. Multiple units bring savings by reducing shunting and dwell times at terminal stations. Six scenarios combining three types of vehicles and two operating concepts are presented. Changes in operating cost items as well as efficiency are quantified using technological procedures, operational measures, and economic tools. The case study shows that diesel multiple units can reduce rail infrastructure use costs by up to 7 % and fuel costs by 5–6 % compared to the current operations. Electric multiple units increase (depending on the operation concept) infrastructure usage costs by nearly 15% but save on traction energy cost and maintenance cost. Battery electric multiple units generate the largest depreciations (up to 28 %) however they save by 5–7 % in traction energy costs compared to electric traction. It is important for stakeholders and policymakers, with the same number of trainsets and staff, it is possible to increase service frequency and thereby improve the supply and quality of regional rail transport.

Keywords: Operating costs, passenger transport, regional railway line, fleet modernization

1. Introduction

The COVID-19 pandemic started a very turbulent period. There has been a very sharp drop in the demand for public transport [1], in carrier´s revenues [2], as well as in the gross domestic product [3]. After the war in Ukraine started, inflation reached ten and more percent in some countries, e.g. in Czechia, and energy and fuel prices have increased. Consequently, an essential part of railway carriers' inputs has become more expensive (traction electric energy, fuel, human labor etc.). Greening of rail transport and the use of renewable sources also cause higher costs [4]. Both transport operators and contracting authorities must look for savings as well as measures that might increase public transport attractiveness. One of possible ways is fleet modernization. This paper shows how this, together with operational changes, can impact carriers' operating costs.

2. Literature Review

Different measures responding to changes in travel behavior, use of public or individual transport, and socio-economic aspects in the context of COVID-19 are proposed by [5]. The technological aspects of operations related to the drop of demand for long-distance rail transport, the impacts of seasonal fluctuations in demand for passenger transport in the period after the pandemic are addressed by [6,7]. The economic aspect of operation is one of the pillars of rail transport sustainability, as stated by [8]. The environmental requirements specified in [9,10] have an essential impact on the economics of rail transport. The LCC of battery electric multiple units (BEMUs) in relation to charging infrastructure addresses [11,12]. Operating and maintenance cost savings due to a reduction in the gross mass of the carriages are reported by [25].

The operating costs of the carrier on the České Budějovice – Jihlava line are as follows [13]: staff costs (train and ticket office staff) 21.5 %, vehicle maintenance 31 %, traction electric energy (TEE) / fuel 11.9 %, capacity allocation and railway infrastructure use 12.9 %, fleet (depreciation) 5.2 %. The low depreciation corresponds to the age of engines and coaches. Staff costs, vehicle maintenance and TEE / fuel create about 65 % of the operating costs of this long-distance line. The shares of the cost items for regional line can be expected to vary depending on new trains, their parameters and stops frequency. Other authors [12,14] report only selected cost e.g. consumption or maintenance.

The literature review shows a lack of scientific publications on the operational-economic aspects of regional rail services. The novelty of our paper can be seen in the combination of an economic, technical, and technological approach to vehicle modernization and the consequent changes in operation concept.

3. V24 Choceň – Náchod Railway Line

The regional line V24 with the operation of semi-fast trains between the Choceň and Náchod stations was chosen for the case study. The single-track line (total length 60.1 km) is not demanding in direction and gradient. It descends from Choceň (292 m about sea level) to Týniště nad Orlicí (249 m) and ascends towards Náchod (347 m). The section Týniště – Choceň (24 km) is electrified. Speed 80-100 km/h is allowed on 55 km of the line (91 % of length).

The current trains are composed of a class 843 railcar and one Btn753 rail carriage. The train capacity is 131 seats. Trains run on a two-hour period, 6 pairs of trains per day, Monday to Sunday.

Two trainsets are needed for regular operation of this line. The travel time in both directions is 59-60 minutes. All 12 trains stop at 7 intermediate stops, and 6 trains stop at one additional station.

3.1 Operating Cost

The total operating costs ($\boldsymbol{C_{op}}$) are calculated as the sum of the seven items (Eq. 1) The passenger carrier must consider all of them when defining its costs. The total operating cost of the railway line also includes the carrier's profit. However, its amount depends on specific conditions (public competition, market consultation, direct award, etc.), it is not included in case study, even if it would increase the total cost.

$$C_{op} = c_f + c_p + c_{ru} + c_m + d + c_c + c_o \quad \text{[CZK]} \tag{1}$$

The mentioned costs include $\boldsymbol{c_f}$ consumption of fuel / TEE, $\boldsymbol{c_p}$ personnel costs (engine drivers, train conductor, event. ticket office staff), $\boldsymbol{c_{ru}}$ use of RI, $\boldsymbol{d}$ vehicle acquisition (depreciation), $\boldsymbol{c_m}$ vehicle maintenance, $\boldsymbol{c_c}$ trains cleaning / tidying. Overheads $\boldsymbol{c_o}$ are included in the analysis and case study, even though their reduction is out of the scope of this paper. The calculations are related to the traffic performance (train-kilometers, trkm) or transport performance (gross ton-kilometers, Gtkm). The input values for the calculations are based on [15], vehicle documentation [16] or expert estimation [17-19].

3.1.1 Fuel Consumption

The specific diesel consumption (s_d) of regional trains (by Czech Railway, ČD) can range between 10-18 liters per 1000 Gtkm [17]. According to statistics of ČD, the average consumption of 843 railcar is 160-200 liters per 100 km [19]. The consumption depends on the gross mass of the train, the height profile of the line and the frequency of stops and partly on train occupancy [12]. The cost of using service facilities c_{sf} e.g. petrol stations, can be reckoned as CZK 1.70 per liter of diesel [15]. For the next calculations, the authors regard these inputs: line length 60.1 km, gross train mass 97.5 t, diesel consumption 14 l/1000 Gtkm [17], coefficient of season period (train heating, cooling) 1.05, coefficient of technological consumption 1.11 [15]. The daily traffic performance of all 12 services p_t = 721.2 trkm. The daily gross performance of the line is p_g = 70,317 Gtkm, diesel consumption c_d = 1,147.7 l/day (on the line). The daily cost of fuel consumption can be calculated according to (Eq. 2):

$$P_{f,V24} = p_d \cdot \left(\frac{s_d}{1000} \cdot M \cdot L \cdot N_L \cdot k_{tc} \cdot k_s\right) + 1.7 \cdot c_d\,, \quad \text{[CZK/day]} \tag{2}$$

$P_{f,V24} = 28 \cdot (0.014 \cdot 97.5 \cdot 60.1 \cdot 12 \cdot 1.11 \cdot 1.05) + 1.7 \cdot 1{,}147.7 = 32{,}126 + 1{,}951 = 34{,}077$ [CZK/day].

where: $P_{f,V24}$ is daily cost of fuel consumption [CZK]; p_d is price of diesel oil [CZK/l]; s_d is diesel consumption [l/1000 Gtkm]; M is gross mass of train [t]; L is distance [km]; N_L is number of services [-]; k_{tc} is coefficient of technological consumption [-]; k_s is coefficient of season period consumption [-]; c_d is daily diesel consumption [l].

3.1.2 Personal Costs – Engine Drivers, Train Conductors

Staff costs – total monthly salary (incl. employer's contributions 33.8 %) of an engine driver (by ČD) was in 2024 CZK 67,000 [15]. The working time of drivers is 36 h per week, i.e. 5.15 h per day, on average 154.5 h per month (30 days). The cost per driver is (rounded) CZK 434 per hour. The number of required drivers per one turn (in two shifts of 12.7 h) is 5.68 incl. 15 % reserve. The daily output, which means one shift $(5.15 \cdot 5.68 \cdot 434)$ implies that the cost of a driver on the line is CZK 12,698 daily, CZK 17.60 per trkm respectively.

The costs of staff per train conductor are calculated in an analogous way: monthly salary (incl. employer's contributions) CZK 53,520. Working time 36 h per week, i.e., 5.15 h per day, 154.5 h per month (30 days); the hourly costs per train conductor are CZK 346 (rounded). The daily costs are CZK 9,266 per day and CZK 12.85 per trkm, respectively.

3.1.3 Capacity Allocation and Railway Infrastructure Use

In the Czech Republic, capacity allocation and the use of railway infrastructure (RI) are charged separately [20]. Fixed amount of the price for capacity allocation is CZK 1,700 per one request (all of services are included in one request). The variable amounts of the charge include the length of the train path and the number of days of train operation. The charge for one train is given by (Eq. 3), for all V24 services per one day according to (Eq. 3a):

$$C_{ca} = F + p_1 \cdot L + p_2 \cdot N_{od}\,, \quad \text{[CZK]} \tag{3}$$

$$C_{ca,V24} = 1{,}700 + 8 \cdot 60.1 + 10 \cdot 12 = 2{,}300.80\,, \quad \text{[CZK/day]} \tag{3a}$$

where: C_{ca} is charge for capacity allocation [CZK]; F fixed amount [CZK]; L train path length [km]; N_{od} number of train operation days [-]; p_1, p_2 constants [CZK], $C_{ca,V24}$ daily charge for all services.

The price for the use of RI by one train has three components – see (Eq. 4). The price component for traffic control is free of charge, so it is not considered in further calculations.

$$C_{RIU} = c_c + c_{tr} + c_{ap} = (b \cdot L \cdot M \cdot t_i \cdot k_{ETCS}) + \sum_{n=11}^{n=15} \left(b_n^s \cdot M_{ap} \cdot N_n^s\right), \quad \text{[CZK]} \tag{4}$$

where: C_{RIU} is charge for RI use [CZK]; c_c is price related to traffic control [CZK]; c_{tr} is price for train running [CZK]; c_{ap} is price for access paths using [CZK]; b is basic price [CZK/stop/train]; M is train gross mass [t]; t_i is train path category [-]; L is route length [km]; k_{ETCS} is coefficient for vehicles equipped with ETCS [-]; b_n^s is basic price for access paths [CZK/stop]; M_{ap} is weight relating to access path using charge [t]; N_n^s is number of stops [-].

The price for $\boldsymbol{c_{tr}}$ depends on $\boldsymbol{b = 0.07306}$ **CZK/1000 Gtkm**, $\boldsymbol{M = 97.5\ t}$, $\boldsymbol{L = 60.1}$ **km** and $\boldsymbol{t_i = 1}$ (for passenger trains). ETCS equipment of an engine and associated discount was regarded until the end of the 2024 only. The 843 railcars have not been equipped with ETCS; therefore, this coefficient can be considered irrelevant. Passenger trains in the Czech Republic are charged for the use of stop access paths [20], depending on the basic price $\boldsymbol{b_n^s}$ per one stop at the *n*-category of stop ($\boldsymbol{n = 11 - 15}$), the number of trains $\boldsymbol{N_n^s}$ which stop at the individual stop´s category, as well as on the weight of the fully occupied train. For current trains $\boldsymbol{M_{ap}} = \boldsymbol{M} = \mathbf{97.5\ t}$. Stations Choceň and Týniště belong to the category 11, Náchod to the category 15; both categories have the same rate $\boldsymbol{b_{11}} = \boldsymbol{b_{15}} = \mathbf{0.07}$ CZK/stop. Other stops go to the category with $\boldsymbol{b_{13}} = \mathbf{0.04}$ CZK/stop. The cost of access paths using (by one train stopping at 9 stations) is $\boldsymbol{c_{ap,9}} = \mathbf{97.5 \cdot [(0.07 \cdot 2) + (0.04 \cdot 6) + (0.07 \cdot 1)] = 43.88}$ CZK. A train stopping in addition at station Čermná increases the price by $\boldsymbol{c_{ap,c}} = \mathbf{97.5 \cdot 0.04 = 3.90}$ CZK. Price for RI use according to (Eq. 4) for all 12 services on the line: $\boldsymbol{C_{RIU}} = \mathbf{12 \cdot (0.07306 \cdot 60.1 \cdot 97.5 \cdot 1) + 12\ \cdot 97.5 \cdot [(0.07 \cdot 3) + (0.04 \cdot 6)] + 6 \cdot 97.5 \cdot 0.04 = 5{,}137.36 + 526.56 + 23.40 = 5{,}687.32}$ CZK/day.

3.1.4 Vehicle Maintenance

The vehicle maintenance depends on vehicle traction, age, and operational performance. In the calculations, the specific costs $p_d^m = 37$ CZK/km for diesel vehicles, $p_e^m = 23$ CZK/km for electric vehicles and $p_c^m = 7.50$ CZK/km for rail carriages are considered [13,17]. Based on these values, according to (Eq. 5), the daily maintenance costs of vehicles p_{V24}^m are determined as:

$$p_{V24}^m = (p_d^m + p_v^m) \cdot L \cdot N_L = (37 + 7.5) \cdot 60.1 \cdot 12 = 32{,}093 \text{ CZK/day}. \tag{5}$$

3.1.5 Vehicle Depreciation

The current vehicles of the line were produced between 1995 and 1997, so the authors consider (according to the real condition) their zero value and therefore the depreciation $d = 0$ CZK. This significantly reduces the cost of the current operation of the V24 line.

3.1.6 Other Costs

The carrier's operating costs also include cleaning and tidying of the trains. According to [15,17], the costs can be reflected as $c_c = 0.70$ CZK/car, for two-carriages train CZK 1.40 per trkm. For two two-carriage vehicles $c_c = 0.70 \cdot 2 \cdot 2 \cdot 6 \cdot 60.1 = 1{,}010$ CZK/day. Another cost item for the carrier is represented by overhead. This cost can be considered as 15-33 CZK per trkm. Due to the turbulent prices of energy, services and materials, the authors rate an upper value i.e. $c_o = 33$ CZK/trkm.

3.2 Total Operating Costs

The total and specific operating costs and the shares of their individual items for the V24 railway line are shown in Table 1. Due to zero depreciation (old vehicles), the highest items in current operation represent fuel and maintenance.

Table 1 Current operating costs items. Source: authors

Cost Item	c_f	c_p	c_m	c_{ru}	d	c_c	c_o
Total [CZK/day]	34,077	21,964	32,093	8,406	0	1,010	23,800
Specific cost [CZK/trkm]	47.25	30.45	44.50	11.66	0	1.40	33
Share [%]	28.1	18.1	26.4	6.9	0	0.8	19.6

The total operating costs for V24 line under the above assumptions and input parameters amount to CZK 121,350, i.e. CZK 168.26 per train-km.

4. Case study: New Vehicles and Impact on Operating Costs

Fleet modernization – purchasing diesel/electric/battery multiple units (DMU/EMU/BEMU) and related operational changes, e.g. additional services in part of the line, reduction of the time for train turnaround, all have an impact on operating costs as follows from the case study below. An assumption for the use of EMUs is the electrification of the section Týniště – Náchod (36.5 km). To operate BEMU, it would be necessary to build a charging infrastructure. The length of the battery-powered section is at the limit of the operating range of most current produced BEMUs [21]. Six operation scenarios are presented, and their costs and efficiency are compared.

4.1 New Vehicles

Due to the age of the current trains (almost 30 years), the first proposal concerns the purchase of new units. The available alternatives are DMU120 (by ČD: 847) and EMU140. Table 2 shows the parameters of both units [22]. In addition, there are parameters of BEMU ČD 690.2 (* estimation).

Table 2 Parameters of new vehicles. Source: authors

Vehicle	Seats	Gross mass [t]	Price [10^6 CZK]	Note
DMU120	115	92	90	ČD 847 RegioFox
EMU140	138	122	117	ČD 650.2 RegioPanter
BEMU140	140	117*	169	ČD 690.2 BEMU

Thanks to the DMU or EMU shunting rides in terminal stations will be not necessary, which will save diesel consumption and time for train turn around. The length of the shunting ride in Náchod is 2,030 m, in Choceň 1,590 m. With 6 circulations at each station, this is 21.72 km daily, by gross mass of 51 t (843 empty railcars) means 1,107.76 Gtkm per day. With a model consumption of 8 liters per 1000 Gtkm [17], this is 8.86 l per day. Considering a diesel price of 28 CZK/liter (excl. VAT), this means a saving of 248 CZK / day of operation, i.e., CZK 90,520 per year.

Downtime reduction in Choceň (from 78 to 9 minutes) has a more significant impact. The saved time can be used for new services to Týniště and back – see trains Nr. 5601-5606 at the Fig. 1; the colors indicate the first and second vehicle turnaround days. Despite the increase of daily traffic and gross transport performance, train staff working regime and number of vehicles will not change.

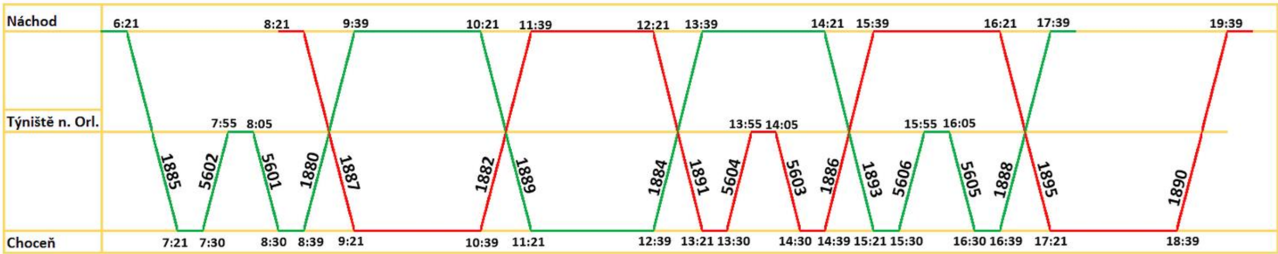

Fig. 1 Graphical timetable of the V24 line with added services. Source: authors

The traffic performance of the new services increases by 141.6 trkm to a total of 862.8 trkm, as well as by transport performance 13,027.2 Gtkm to a total of 79,377.6 Gtkm per day. The costs of these additional performance will be compensated based on public service obligation of both regional Authorities (the line connects cities in the Hradec Králové and Pardubice regions).

4.2 Railway Infrastructure Use

The new DMU is 5.5 t lighter; therefore, the price for RI use will be lower (with the same base prices and the same number of stops). On the other hand, EMU is almost 25 t heavier, which causes the opposite effect. In variant 2 and 4 (see below) there are additionally 3 stops: 1 regular stop of category $b_{13}^{s} = 0.04$ CZK/stop and 2 request stops of category $b_{15}^{s} = 0.07$ CZK/stop (together considered as one regular stop). The cost of the capacity allocation for the additional 6 trains is negligible: it increases by 248.80 CZK/day i.e. 1.76/trkm. The price for the use of access paths will increase by CZK 60.72 per day, i.e. CZK 0.43 per trkm for variant 2 (see below) and by CZK 80.52 daily, i.e. CZK 0.57 per trkm for variant 4.

4.3 Fuel and Traction Energy Consumption

The consumption depends mainly on the type and traction of vehicles [12], their gross mass, but also on the track parameters and frequency of stops [23]. To quantify the impacts of purchasing new trains and operation with / without added services, two variants are anticipated for DMUs (operation unchanged; operation with added services) and other two variants for EMUs are anticipated. The same price of diesel and TEE is considered as input values for calculation of fuel and TEE costs. For comparison, two BEMU operation scenarios are added (see Tab. 3, Fig. 2).

4.3.1 DMU, Diesel Consumption

Variant 1: DMU, current operation – diesel consumption for V24 line is based on these parameters: specific consumption 14 l/1000 Gtkm, 847 unit´s gross mass $M = 92\ t$, daily traffic performance 721.2 trkm, transport performance 66,350.4 Gtkm. According to (Eq. 2), the daily consumption $c_{d1} = 1{,}082.64$ liters of diesel, i.e. by price 28 CZK/liter CZK 30,313.91 and CZK 44.58 CZK/trkm.
Variant 2: DMU, 6 additional services (passenger trains) – consumption of 16 l/1000 Gtkm (due to more frequent stops); additional daily traffic performance of 141.6 trkm, daily transport performance

13,027.2 Gtkm. According to (Eq. 2), the additional daily diesel consumption $c_{d2} = 242.93$ liters. The daily cost is the sum of costs of both variants 1 and 2, in total 37,116 CZK and 43.02 CZK/trkm.

4.3.2 EMU, TEE Consumption

After electrification (AC traction) of the section Náchod – Týniště, the EMU with parameters according to Table 2 can be considered. For total daily TEE consumption, see (Eq. 6). The loss coefficient $k_l = 1.14$ is added to (Eq. 2) as well as coefficient of savings from regenerative braking (20 %). Specific consumption 40 kWh for semi-fast train and 50 kWh/1000 Gtkm for stop-train correspond with the values mentioned in [14,24].

$$S_{ttc} = \frac{s}{1000} \cdot M \cdot \sum_{i=1}^{n} L_i \cdot N_{Li} \cdot k_l \cdot k_s \cdot k_{tc} \cdot r, \quad \text{[kWh]} \tag{6}$$

where: S_{ttc} is total daily TEE consumption, s is the specific consumption [kWh/1000 Gtkm]; L_i [km] is the length of the i-section (here 2 sections); N_{Li} is the number of services on the i-section; k_l is the loss coefficient [-]; M, k_s, k_{tc} [-] see (Eq. 2); r is the coefficient of regenerative braking [-].

Variant 3: EMU, current operation – specific TEE consumption can be rated as 40 kWh per 1000 Gtkm for semi-fast train, gross mass 122 t, $\boldsymbol{r = 0.8}$. The daily consumption for the line $\boldsymbol{S_{ttc}}$ = 3,740.96 kWh, i.e. 11,376.26 CZK and 15.77 CZK/trkm.

Variant 4: EMU and 6 additional services (passenger trains) – specific TEE consumption for stop-trains is considered as 50 kWh/1000 Gtkm. The daily consumption of the added services is 918.12 kWh. With the consumption of the original services (Var. 3), the TEE consumption $\boldsymbol{S_{ttc} = 122 \cdot \left(\frac{40}{1000} \cdot 60.1 \cdot 12 + \frac{50}{1000} \cdot 23.6 \cdot 6\right) \cdot 1.14 \cdot 1.05 \cdot 1.11 \cdot 0.8 = 4{,}659.08}$ kWh i.e. 14,168.26 CZK per day, it means 16.42 CZK per trkm.

4.4 Vehicle Depreciation

New vehicles, owned by the carrier, depreciate. Vehicles can be depreciated for 30 years. The railway line in question needs to be operated by two trains (units). To determine the amount of depreciation, these inputs are reckoned: price of DMU = CZK 92 million, price of EMU = CZK 117 million, daily $p_t^1 = 721.2$ trkm (original), $p_t^2 = 862.8$ tkm (added services), availability coefficient k_a= 0.9, i.e. 328 operating days in year. Eq. 7 gives the depreciation for vehicles of the *i*-traction ($i = 1$, diesel), $i = 2$, electric) and *j*-variant of operation:

$$d_i^j = \frac{p_i \cdot n_v}{n_y \cdot n_d \cdot k_a \cdot p_t^j}, \quad \text{[CZK/trkm]} \tag{7}$$

where: d_i^j is depreciation [CZK/trkm]; p_i is price of unit [CZK]; n_v is number of vehicles [-]; n_y is number of depreciation years [-]; n_d is number of days in year [-]; k_a is availability coefficient [-]; p_t^j is daily traffic performance by j-variant [trkm].

Depreciation for the operation of variant 1, i.e. DMU and current operation $\boldsymbol{d_1^1} = \frac{\mathbf{92\,000\,000 \cdot 2}}{\mathbf{30 \cdot 365 \cdot 0.9 \cdot 721.2}} = \mathbf{25.93}$ CZK/trkm. Analogically, the depreciation of variant 2 (DMU, added services): 21.67 CZK/trkm; variant 3 (EMU, current operation): 32.97 CZK/trkm and variant 4 (EMU, added services): 27.56 CZK/trkm.

4.5 Cost Efficiency

The cost efficiency e^j of the j-variant (operation scenario) per passenger kilometer [pkm] can be calculated as $e^j = \frac{C^j}{S \cdot \omega}$ [CZK/pkm], where $C^j$is cost [CZK/trkm] of j-operation scenario ($j = 1 - 6$), S is train seat capacity [-], ω [-] average train occupancy; $\omega = 0.2 - 0.25$ can be considered for regional trains [17]. The cost efficiency of each operation scenarios (for $\omega = 0.25$) is shown in Table 3.

5. Discussion

The results of the analysis and the case study should be seen in the context of the conditions and input values. Change in specific values (consumption, diesel / TEE price) would imply a change in the operating cost. The prices of the vehicles will vary for each purchase depending on the lowest bid of the tenderers. The DMU / EMU / BEMU prices correspond to the winning prices in the ČD tenders for the acquisition of its vehicles. Table 3 shows the shares [%] of costs items as well as cost efficiency CZK/pkm] for each operation scenarios. BEMU costs were calculated analogously according to (Eqs. 2–7) with the input data according to Table 2 and [18]. BEMU c_f is the sum of TEE consumption on the electrified (from the pantograph) and non-electrified section (from battery).

Table 3 Cost shares and efficiency of operation scenarios. Source: authors

	c_f	c_p	c_m	c_{ru}	d	c_c	c_o	e^j
Current operation shares [%]	28.1	18.1	26.4	6.9	0	0.8	19.6	5.14
Shares [%] according to scenario								
Var. 1: DMU basic	24.4	16.6	20.2	6.1	14.2	0.5	18.0	6.37
Var. 2: DMU new services	26.1	14.6	21.2	6.2	12.4	0.7	18.9	6.08
Var. 3: EMU basic	10.5	20.3	15.4	9.2	22.0	0.6	22.0	4.34
Var. 4: EMU new services	11.7	18.2	16.4	9.6	19.7	0.8	23.6	4.06
Var. 5: BEMU basic	8.9	18.1	16.6	7.9	28.3	0.5	19.6	4.81
Var. 6: BEMU new services	9.8	16.4	18.0	8.3	25.6	0.8	21.2	4.45

The operation scenarios (var. 1 – var. 6) show the following for regional line:

- the DMUs (ČD class 847), despite their relatively high consumption, can give about 11 % savings in fuel costs due to lower gross mass.
- the EMU will bring significant savings in TEE costs (64-66 %) compared to the current diesel trains as well as to the new DMU. The acquisition of EMU also means lower maintenance costs. The largest depreciation of EMU is in the 'base' operating (variant 3).

- the change in operation concept (added services, reduction of downtime in Choceň) will generate a reduction in staff costs. The scenarios with added services (variants 2, 4, 6) show that the using engine drivers' and train conductors' working time increases from the current 47 % (6 h driving, working from 12.7 h shift) to 76 % (8.5 h).
- the costs of RI use are lowest (7 % under the current costs) in case of new DMU and added services. Heavier EMUs increase the share of c_{ru} in the total price per trkm by 2–2.6 %.
- compared to the long-distance line [13], the train staff costs for the regional line are almost the same (we do not consider the ticket office staff) – the variation is around 3 %; there is a similar situation for maintenance and charges for the RI use. Fuel consumption costs are significantly higher (up to 16%) in case of regional line in current operation.
- current costs efficiency e = 5.14 CZK/pkm due to zero depreciation; new operational efficiency e^j varies from CZK 4.06 (EMU, added services) to CZK 6.37 per pkm (DMU basic).

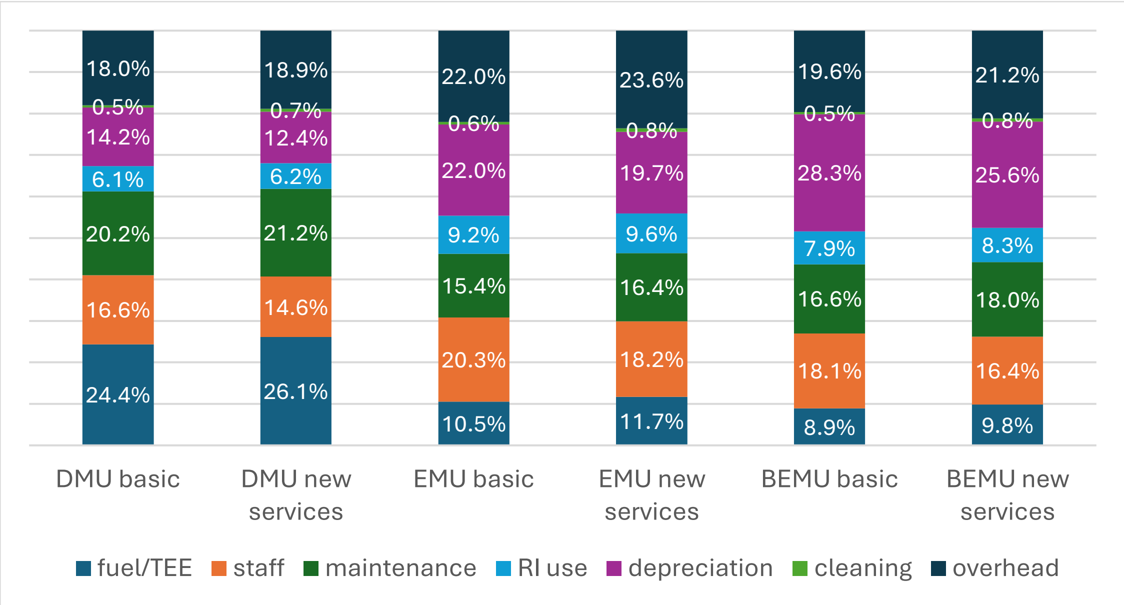

Fig. 2 Shares of operating costs according to scenarios. Source: authors

- BEMU operation with current p_t is almost as expensive as old trains operation. Total operating costs will decrease around 7 % in BEMU scenario with additional services comparing to current operation.
- BEMU operation generally means high depreciation (26–28 %), but also savings in energy consumption (slightly lower than EMU). A 10 % reduction in the purchase price of BEMU would mean a reduction in total costs 2.6–2.9 % depending on the operation concept.

6. Conclusion

Fleet modernization is an opportunity for stakeholders to consider changes in the operation concept. It may be inspiring that 19 % increase in traffic performance (more services, better transport offer) means an increase in operating costs of approximately 6% only.

More energy-efficient and environmentally friendly vehicles (EMUs and BEMUs) generate up to twice as much depreciation as DMUs, but TEE costs can be up to two-thirds lower than for DMUs. The acquisition of multiple units in combination with a change in the operation concept can also lead to a more efficient use of train staff working time. Maintenance costs represent 15-21 % of total costs depending on the acquisition way (buy, leasing, full service, etc.). The railway infrastructure use costs depend on the gross weight of the vehicle, which is why they are lowest for lighter DMUs.

Crucially, the proposed changes do not require additional vehicles or staff. The combination of new vehicles and the change of the operation concept (EMU, additional services) can save up to 17 % in operating costs (a total CZK 140 per trkm), mainly due to reduced TEE consumption, better utilization of staff working hours, and lower maintenance costs. The most expensive (CZK 183 per trkm) operation is the DMU scenario with current services. BEMU operation with additional services on part of line can bring total costs savings of up to 7 % compared to current (old trains) operation.

Acknowledgements

This paper presents some findings of the project Reg. Nr. SGS_2023_017 "Modeling of selected Aspects of Traffic Control and Technology III" supported by University of Pardubice.

References

[1] Smolarski, M. (2020). Restrictions on regional passenger transport during epidemiological threat (COVID-19) – an example of the Lower Silesian Voivodship in Poland. Prace Komisji Geografii Komunikacji PTG 23(2), 56-61. DOI: 10.4467/2543859XPKG.20.009.12107.

[2] Jugović, A., Aksentijević, D., Budić, T. & Oblak, R. (2022). Impact of COVID-19 pandemic on passenger mobility in national and international railway traffic of the Republic of Croatia. Pomorstvo 36(1), 147-154. DOI: 10.31217/p.36.1.17.

[3] Rothengatter, W., Zhang, J., Hayashi, Y., Nosach, A., Wang, K. & Oum, T.H. (2021). Pandemic waves and the time after Covid-19–Consequences for the transport sector. Transport policy, 110, 225-237. DOI: 10.1016/j.tranpol.2021.06.003.

[4] Riha, Z., Dockalikova, I., Tichy, J. & Koštiaľ, D. (2022). Solving transportation externalities, economic approaches, and their risks. Open Engineering 12(1), 1-10. DOI: 10.1515/eng-2022-0001.

[5] Henrion, V., Ingvardson, J.B. & Nielsen, O.A. (2023). The Influence of the COVID-19 Pandemic on Travel Behavior in the Greater Copenhagen Area. Journal of advanced Transportation 2023(1), 1-12. DOI: org/10.1155/2023/9964912.

[6] Dedík, M., Zitrický, V., Valla, M., Gašparík, J. & Figlus, T. (2022). Optimization of Timetables on the Bratislava–Žilina–Košice Route in the Period after the End of the COVID-19 Pandemic. Sustainability 14(9), 5031. DOI: org/10.3390/su14095031.

[7] Heřmánková, A. & Kleprlík, J. (2024). Issues of providing transport services to sparsely populated areas: a case study of the territory of the National Park Šumava in the Czech Republic. Transport Problems 19(2), 109-122. DOI: 10.20858/tp.2023.19.2.09.

[8] Říha, Z. & Tichý, J. (2015). The costs calculation and modelling in transport. In Proceedings of the Transport Means international scientific conference, October 21-22, 2015 (pp 388-391). Kaunas University of Technology.

[9] The European Parliament and the Council. (2019). Directive (EU) 2023/959 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading. Retrieved October 30, 2025, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023L0959

[10] Green Deal. (2019). Retrieved October 30, 2025, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640&qid=1761810136020

[11] Streuling, C., Pagenkopf, J., Schenker, M. & Lakeit, K. (2021). Techno-Economic Assessment of Battery Electric Trains and Recharging Infrastructure Alternatives Integrating Adjacent Renewable Energy Sources. Sustainability 13, 8234. DOI: 10.3390/su13158234.

[12] Herwartz, S., Pagenkopf, J. & Streuling, C. (2020). Sector coupling potential of wind-based hydrogen production and fuel cell train operation in regional rail transport in Berlin and Brandenburg. International Journal of Hydrogen Energy. DOI: 10.1016/j.ijhydene.2020.11.24.

[13] Froněk, J., Kudláč, V., Porwisz, V. & Vymětal, D. (2019). Offer of transport services on a long-distance railway line – costs, revenues, compensation. Nová železniční technika: nové železniční trendy 27(6), 24-27.

[14] Ghaviha, N., Campillo, J., Bohlin, M. & Dahlquist, M. (2017). Review of Application of Energy Storage Devices in Railway Transportation. Energy Procedia 105, 4561-4568. Retrieved January 24, 2024, from https://www.sciencedirect.com/science/article/pii/S1876610217310950. DOI: 10.1016/j.egypro.2017.03.980.

[15] Zitko, J. (2024). Railway Passengers Carriers Cost Savings. Unpublished Diploma Thesis, University of Pardubice, Pardubice.

[16] ŠKODA Transportation. Technical documentation of EMU, BEMU. Retrieved August 26, 2025, from https://www.skodagroup.com/cs/reference/bateriova-elektricka-jednotka-regiopanter

[17] Pohl, J. (2025). Costs and Revenues in Passenger Rail Transport (In Czech, „Náklady a výnosy v osobní železniční dopravě“). Unpublished presentation. Pardubice. April 4, 2025.

[18] Šindel, R. (2024). Possibilities for the Deployment of 25 kV BEMU on the Czech Railway Network (In Czech, „Možnosti nasazení 25 kV BEMU na české železnici“). Retrieved September 10, 2025, from http://www.perner.cz/Seminare/Ids_2024_zaver/02-01-Sindel.pdf

[19] České dráhy. (2025). Internal statistics of DMU consumption. Received by e-mail at 2025-02-05.

[20] Správa železnic. (2025). Network Statement for the 2025 schedule. Retrieved on August 14, 2025, from https://www.spravazeleznic.cz/dopravci/prohlaseni-o-draze-2025

[21] Baran, F. & Molková, T. (2023). Zero-Emission Regional Transport in Relation to Future High-Speed Rail Lines in the Czech Republic (In Czech, „Bezemisní regionální doprava v souvislosti s budoucími vysokorychlostními tratěmi v ČR“). Vědeckotechnický sborník Správy železnic 8, 98-123.

[22] ČD. (2025). Report on the Purchase of Battery Trains. Retrieved on August 27, 2025, from Zdopravy.cz

[23] Ćwil, M., Bartnik, W. & Jarzębowski, S. (2021). Railway Vehicle Energy Efficiency as a Key Factor in Creating Sustainable Transportation Systems. Energies 14 (16), 5211. DOI: 10.3390/en14165211.

[24] Network Statement ÖBB-Infrastruktur AG. (2025). Retrieved on February 15, 2025, from https:// infrastruktur.oebb.at/en/partners/rail-network/network-statement/network-statement-2025

[25] Bulakh, M. (2025). Improving the technical and operational characteristics of the railway carriage. Scientific Reports 14(1):509. DOI: 10.1038/s41598-024-84332-0.