Acta Polytechnica CTU Proceedings **43**:62–71, 2023
https://doi.org/10.14311/APP.2023.43.0062

MODERN VEHICLES FOR REGIONAL RAILWAYS

Josef Kolář

Czech Technical University in Prague, Faculty of Mechanical Engineering, Department of Automotive, Combustion Engines and Railway Engineering, Technická 4, 160 07 Prague, Czech Republic

correspondence: josef.kolar@fs.cvut.cz

Abstract. The paper analyses the history of two-axle rail vehicles (rail buses) used for operation on regional lines in Czechoslovakia. It also shows trends in the development of modern light autonomous rolling stocks usable for passenger transport on unprofitable regional lines in Western Europe. The measures adopted in the transport policy of the Czech Republic for the period 2021–2027 for regional railway vehicles in the Czech Republic are presented. The final part of the paper presents the results of study of the concepts of a two-axle hybrid and electric rail buses and a conceptual design of a modular solution of a partially low-floor vehicle BEMU and HEMU for passenger regional rail transport. This paper shows that it is very problematic to create a light rail vehicle (LVR) that will be economical and environmentally friendly for regional transport and at the same time will meet the requirements of standards ČSN EN 12 663, category P2 and ČSN EN 15 227, category C I and will be friendly to road users.

Keywords: Modern railways, regional vehicles, rail bus, design vehicles, light rail vehicle, often low-floor rail vehicle, motor rail vehicles.

1. Introduction

Railway companies have been tackling the idea of offering reliable, safe and economically acceptable regional rail transport on non-electrified low-traffic lines since the mid-1920s. The logical development step was the motorization of the vehicle fleet, i.e. the replacement of regional steam passenger trains by light rail buses, derived from road bus constructions, such as the Skoda 550. Also for example 1 pc of Praga M120 and 11 pcs of Skoda M 120.1 rail buses, which were supplied in that time for CSD, can be stated, see Figure 1.

Figure 1. One-way rail bus Skoda M 120.1 when turning using its own turntable [1].

After the Second World War, the concept of a light railway vehicle, a rail bus for a regional railway, was represented by the M 131.1 motor car, see Figure 2, which was manufactured in the years 1948–1956 in the Tatra Vagonka Studenka company in the number of 549 pieces. In operation from 1948 to 1984 and significantly unified the CSD fleet used for regional transport. This two-way trafic, two-axle motor car weighting approx. 16.6 tons powered by an air-cooled, twelve-cylinder diesel internal combustion engine from a Tatra 111 truck. To prolong the life of the internal combustion engine, its power was reduced to 120 kW for the needs of the M 131.1 and it was supplemented with an oil cooler, as the installation of the internal combustion engine in the car did not allow air-forced cooling. The M 131.1 passenger motor car with the axle arrangement (1A) reached a maximum speed of $V = 60\,\mathrm{km\,h^{-1}}$ and had a transport capacity of 48 seats.

Figure 2. Two-way motor car M 131.1 – Hurvinek [2].

Since 1973, the M 131.1 motor cars were gradually replaced by new light two-axle motor cars M 152.0, class designation 810, of which about 680 pieces were produced for CSD. In addition to these motor vehicles, company Vagonka Studenka also produced approximately 912 pcs Blm 24–29 trailer cars, class designation 010 see Figure 3. Between 2006 and 2012, 210 pcs of these vehicles underwent a partial modernization. The main requirement of of the modernization was to create a light, partly low-floor vehicle for regional transport, class 814. It can be stated that RegioNova in a two-car (814 + 914), see Figure 4, or three-car (814 + 014 + 814) arrangement represented a compro-

Figure 3. Motor car M 152 + trailer (810 + 010) [3].

Figure 4. Two-car unit RegioNova (814 + 914) [3].

mise solution of partial low-floor and modernization. However, even the two-car version seems to be uneconomical for low-traffic regional lines in the Czech Republic, as the hydrodynamic power transmission does not allow energy recovery [3].

2. Regional Railways – Profitability, Safety and Filling of the Goals of the Project “Vision O”

Other countries in Europe are also facing the problem of profitability of regional lines. In the next part of the paper, I will try to outline the visions of the modern regional transport on low-traffic lines in France, England and Germany.

As a result of the discussion that took place in France in 2018, it was stated that about 9000 km of regional lines are not competitive and should be closed. Régis Coat, President of EXID Concept & Developpement, who presented the Taxirail project, which aims to secure the future of low-passenger regional routes using small light autonomous rolling stock running seven days a week and 24 hours a day, disagrees. In France, it is possible to operate Taxirails on the same lines as freight trains. There is a maximum of two freight trains a day on small regional lines, says Coat. “We have taken measures to avoid having Taxirail and freight trains on the line at the same time” [3].

Taxirail vehicles, see pictures Figure 5, should drive fully automated, with a degree of automation (GoA) 4, i.e. without a driver. Whether the Taxirail project will be a realistic and viable solution should be demonstrated by feasibility studies for the CAux-SEine Agglo

Figure 5. Taxirail autonomous vehicle concept [4–6].

agglomeration between Le Havrea and Roun, which was to be launched in September 2021.

The standard autonomous light rail vehicle Taxirail should be 6 m long and 2.9 m wide with a maximum speed of 100 km h^{-1}. It is to be deployed on tens of single-track, non-electrified lines in France with a length of 10 to 80 km. Each vehicle will have 16 seats and space for 40 passengers. To reduce the weight of the Taxirail to 11 tonnes, they will not be manufactured to the strict crash resistance standards of conventional trains. However, the current national rules for the operation and construction of trains will need to be rewritten for Taxirail and stakeholders are being consulted [5, 6].

RAILBUS Inc. presents a similar solution for the rail transport with the help of light autonomous vehicles without a driver, which is more suitable for the urban transport. RAILBUS vehicle with a light body mounted on two two-axle bogies, see pictures in Figure 6, offers a transport capacity of 22 seated and 18 standing passengers and a maximum speed of 100 km h^{-1} [7].

An interesting feature of this transport system is

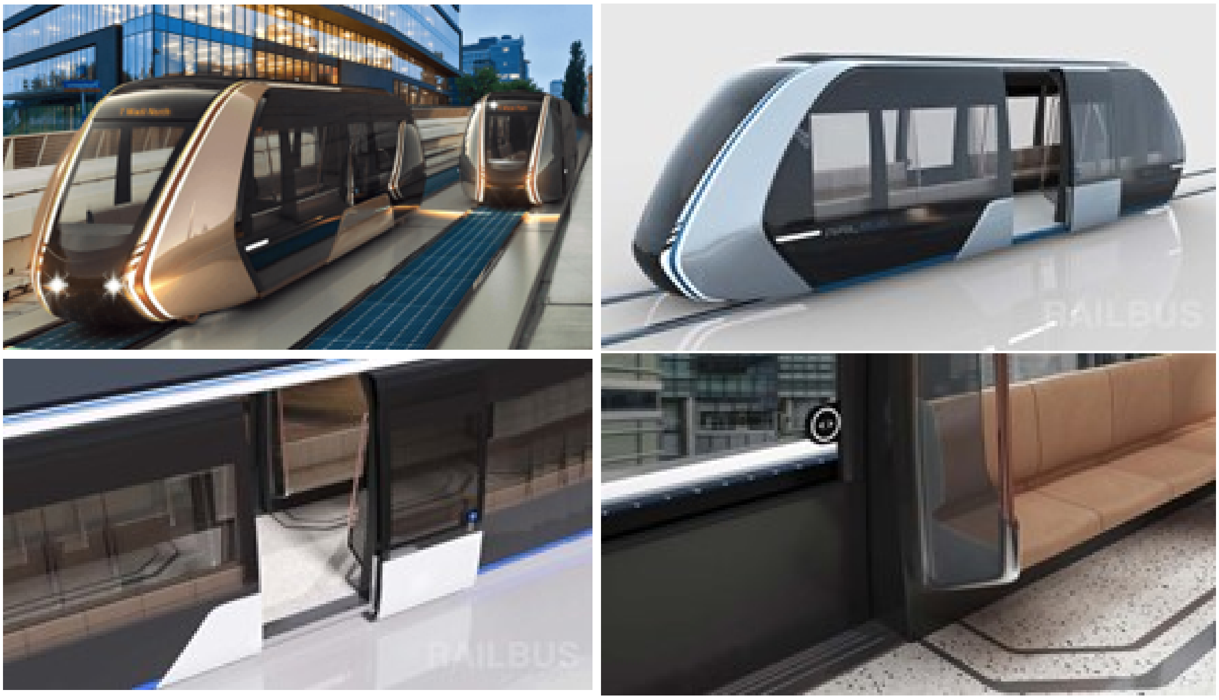

Figure 6. Vehicle RAILBUS [7].

the fully solar vehicle power supply system, where the solar panels are located in the track. This solution will probably not be used for the needs of local regional railways, as it would probably require to consistently isolate these sections of the track from the surrounding environment [7].

Within the development of light autonomous tram vehicles, see Figure 7, graduates of U 12 120, FME CTU, today employees of Skoda Transportation, are involved as well.

An interesting solution of rail transport with the help of light rail vehicles with a driver, which is rather suitable for urban transport, was presented by the British company TDI for the city of Coventry, see pictures Figure 8. A light construction vehicle with a length of 11 m, a width of 2 650 m and a height of 3 175 m offers a transport capacity of 20 seated and up to 50 standing passengers. Minimum traction power 175 kW and maximum vehicle speed up to 70 km h^{-1} and weight approx. 11 tons [8].

Another inspiring light rail vehicle solution for regional transport is the autonomous battery electric rail bus Aachener Rail Shuttle (ARS), developed at the Institute for Rolling Stock and Transport Systems of the RWTH in Aachen, see Figure 9. The electric bus is 12 m long. The running gear with a wheelbase of 8 m forms the robust main frame of the vehicle, which is supported on two traction wheelset via the primary suspension. The force effects during an accident are captured only by this main frame, which is dimensioned according to category C-III of the EN 15227 standard. To absorb the impact energy, impact elements (purple colors) are attached to both ends of the vehicle frame [11].

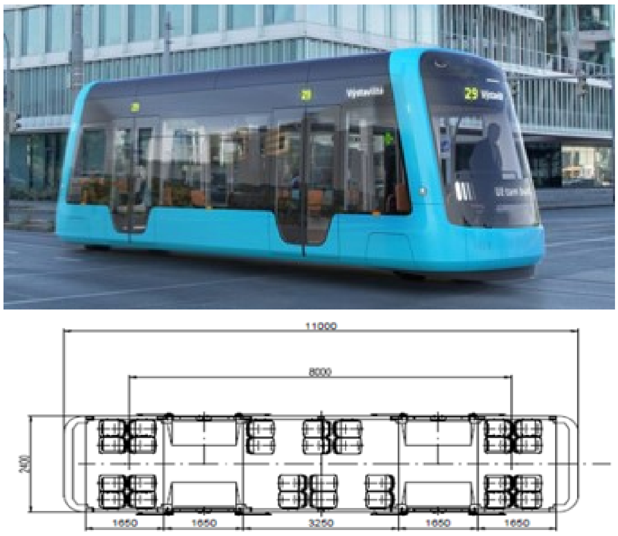

Figure 7. Possible solution for a two-axle autonomous tram presented by ŠKODA [9, 10].

An over 3 m wide lightweight car body is placed on the chassis frame via a pneumatic suspension, which in the 2+2 seating arrangement is equipped with 34 fixed seats and eight folding seats installed in the boarding areas. The rail bus is supposed to carry a maximum of 90 passengers. Each axle is driven by an electric motor with a nominal power of approx. 150 kW, which provides a pulling force of up to 40 kN at a maximum acceleration of 1.5 m s^{-2}. The mass of the empty vehicle is to be less than 17 t, which would result in a maximum weight of 25 t with a payload of up to 8 t. The maximum wheelset load would thus be only 12.5 t [11].

Figure 8. Concept vehicle COVENTRY LVR [8].

Figure 9. Concept vehicle ARS BUS [11].

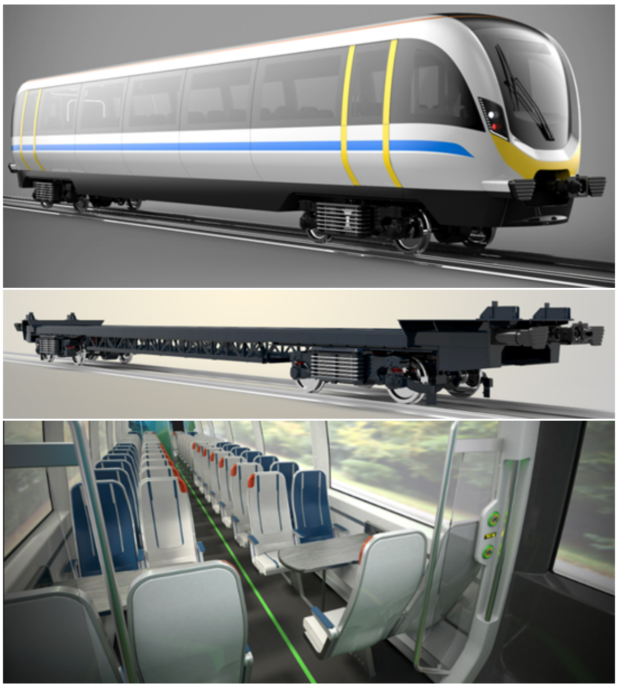

FIGURE 10. Revolution Very Light Rail [12].

The concept of light rolling stock for regional railways in England is represented by a solution developed by the University of Warwick, see Figure 10. The two-way diesel-electric Revolution VLR is produced by a consortium led by Transport Design International. The vehicle, the rail-bus is 18.5 m long, 2.8 m wide and 3.8 m high, offers 120 places for passengers, including 56 seats, and a maximum speed of 104 $\mathrm{km\,h^{-1}}$ [12].

The hybrid drive is provided by a power pack of a diesel combustion engine with an electric generator located in the chassis and a battery power pack (lithium titanium LTO) or lithium manganese cobalt oxide (NMC), which will be recharged by a recuperation or by a trolley wire if the track is electrified. The wheelsets are powered by electric motors, see Figure 11.

The rail bus is not equipped with a WC module and apparently do not offer space for the transport of bicycles and strollers. The designers calculate a specific weight of 1 ton per 1 meter of car length. Therefore the total weight should not exceed 18 tons. Due to such a low weight, the cabinets are not sufficiently strong and crash resistant, by standard EN 12 663, category P2 and to category C-III of the EN 15227 standard. The units will be used on small regional lines or suburban lines where there is no danger of collisions with freight trains or other larger trains. The high-floor design of the vehicle does not allow its use on regional lines in the Czech Republic, where the edge of the platform is 600 mm above the level of the top of the track.

In the next part of the paper, we will see what is the aim the Czech Republic wants to take in regional transport.

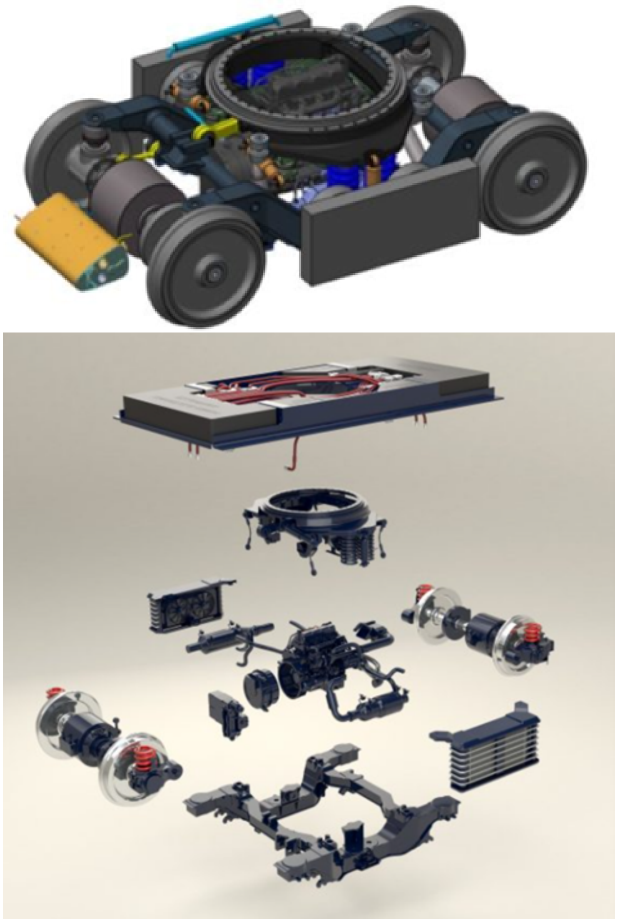

FIGURE 11. Bogie for Revolution Very Light Rail [12].

3. Transport Policy of the Czech Republic for the Period 2021–2027

The Czech Republic is one of the countries with the highest density of railway lines in Europe. There are approximately 0.12 km of tracks per 1 $\mathrm{km^2}$. In 2021, 9 377 km of state-owned railway lines and over 100 kilometers of regional lines owned by other entities were in operation. A large share of the railway network, approx. 80 %, consists of regional lines, on which only approx. 10 % of the transport capacity is ensured. Nevertheless, it can be stated that even these lines have their influence on ensuring the serviceability of the territory and their importance may increase with the adoption of the measures specified in the transport policy of the Czech Republic for the period 2021–27.

In the material Transport policy of the Czech Republic for the period 2021–2027 with a view to 2050, it is stated on page 38 [13]:

"On the railways, a pan-European trend is visible, which will gradually lead to the termination of the diesel traction. Battery-rail cars will be gradually introduced in combination with progressive electrification (bimodal cars can also be used temporarily), which will serve non-electrified end sections and which will be continuously dynamically charged at driving along elec-

trified sections, or statically charged while standing in electrified stations. Therefore battery-rail cars are not a replacement for the line electrification, but a supplement to it."

The renewal of vehicles must also respect the requirements for alternative types of drives, taking into account the gradual process of electrification of other lines. The expansion of these types of drive will most likely be associated with a significant increase in compensation to carriers, paid by the customer. With respect to the proposed measures listed on page 39, the following measures are particularly interesting for regional railway vehicles [13]:

- **1.3.1.5** Create facilities for the operation of battery vehicles in areas without a line electrification, by building power points both for overnight stay of vehicles (heating) and for charging vehicles at turning stations.
- **1.3.1.6** Coordinate the plans of the Ministry of Transport of the Czech Republic and Railway Administration state enterprise (SZ) for the electrification of other lines with the plans of the carriers for the development of the vehicle fleet, so that investments are not wasted. In practice, this means no longer buying vehicles powered by internal combustion engines and focusing financial resources exclusively on the purchase of electric vehicles (trolley-powered or battery-powered).
- **1.3.1.7** Coordinate the plans of the Ministry of Transport of the Czech Republic and SZ for the electrification of other lines with the plans of the Ministry of Transport of the Czech Republic and Railway Administration state enterprise (SZ) to equip tracks and vehicles with the unified European train safety system ETCS. The goal is that the tracks that have not been electrified yet, will also be electrified at the same time when they are equipped with the unified European train safety system ETCS. In this way, an inefficient investment into the equipment of unpromising diesel-powered vehicles with the mobile part of the ETCS train security system can be avoided, as these will be discontinued in the foreseeable future.
- **1.3.1.8** Coordinate the plans of the Ministry of Transport of the Czech Republic and Railway Administration state enterprise (SZ) for the electrification of other lines with the plans of the public transport customers to solve line management and requirements for vehicles. Do not allow transport provided by diesel-powered vehicles to be ordered on electrified lines and do not allow public transport customers (state and regions) to demand new diesel-powered vehicles from carriers to provide transport.

4. Study of Rail Vehicle for Regional Transport in the Czech Republic

Regional lines in the Czech Republic quite often (approx. 8 000 times) cross in the form of level crossings with varying degrees of security with local roads. Every unprotected crossing increases the risk of an accident between a regional train and a road vehicle. However, to solve this danger by requiring compliance with EN 12 663 in the P2 category and EN 15 227 in the C I category means that economically and environmentally beneficial light two-axle motor vehicles, referred to as rail buses, will disappear from regional transport. We came to this conclusion based on conceptual studies of a hybrid rail bus and an electric bus, see Figure 12. The results of these studies were presented at conferences [3, 4].

Wouldn't it be more appropriate to introduce contractually and clearly defined operating rules on regional lines that would determine when during the day there will be a regular passenger traffic and at what time intervals an irregular freight traffic can be carried out? Isn't this an idea that, with proper use of ETCS and IT technology, could simply prevent a possible collision between a freight train and a light rail vehicle?

Is it appropriate to "dope" rail vehicles for passenger regional transport with robust passive safety elements that increase their weight, lengthen their starting and braking distance, increase energy consumption and reduce their competitiveness with respect to the road bus transport? Are we not taking these steps against the ideas of our predecessors about an economical regional railway implemented in the passenger transport with light rail vehicles?

I would like to point out that meeting the requirements of standards EN 12 663 (category P2), EN 15 227 (category C I) creates a clear winner in a collision with a passenger car from a rail vehicle. Most of these accidents result in significant destruction of the passenger car and serious injuries or death of the car crew members. These accident results go against the ideas of the European "Vision 0" project on road and rail.

In order to create "friendly" regional rolling stock, it would be more appropriate to demand compliance with the requirements of the EN 12 663 standard in the P3 category and the EN 15 227 standard in the C II category, and to equip rail and road vehicles with active safety elements that would significantly eliminate the possibility of their mutual collision. The requirement for the introduction of ETCS-level 2 will certainly significantly contribute to a higher level of active safety of rail traffic in regional transport.

However, the next, completely logical step should be the initiation of an intensive cooperation between ETCS creators and manufacturers of a car navigation and control systems. Transferring information about

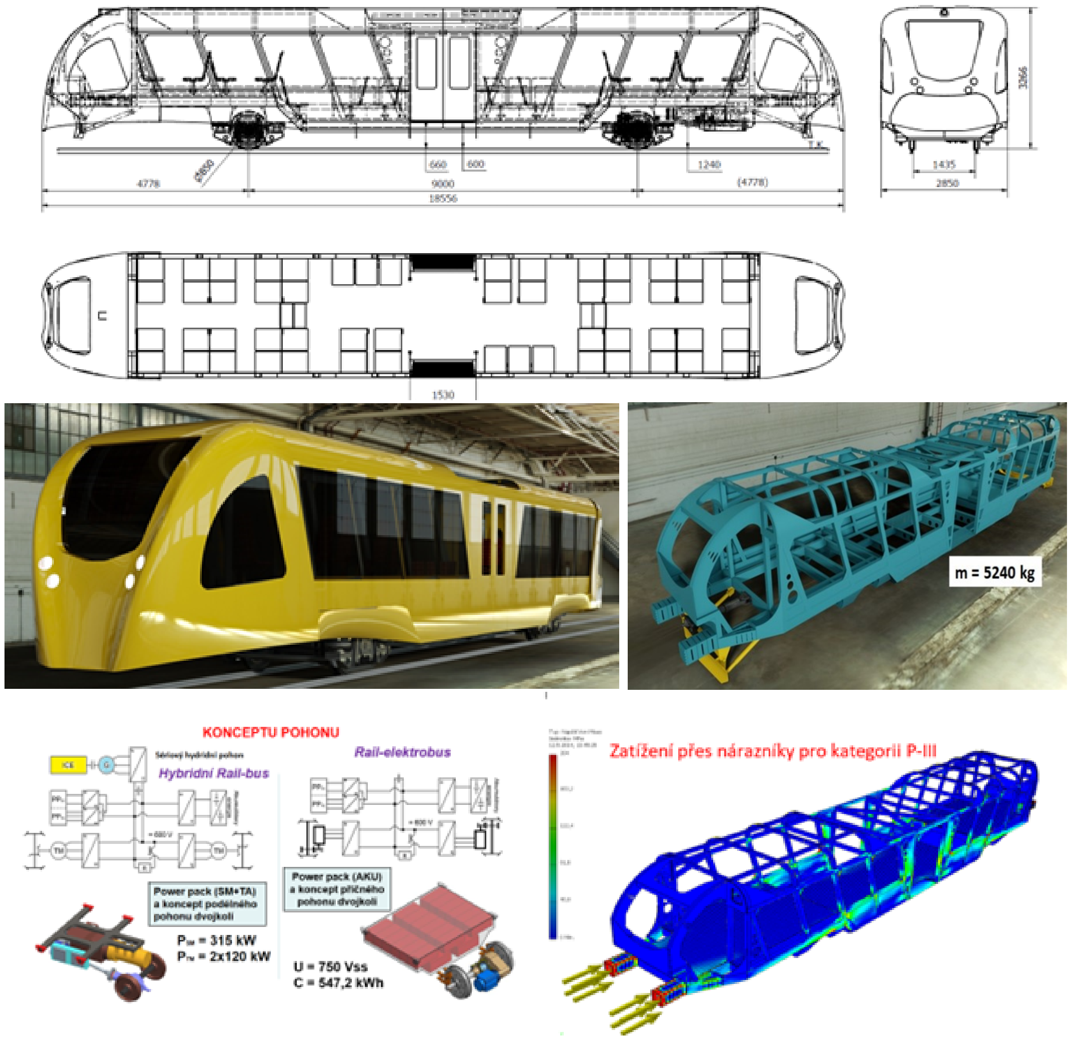

FIGURE 12. Concept of the Hybrid Rail-bus or the Rail electrical-bus [14].

the position of the train to the navigation and control unit of the car, displaying it to the driver and storing it in the recording device of the "black box of the car" can contribute to a significant increase in the responsibility of car drivers for their behaviour at unprotected railway crossings. This cooperation of the mobile part of ETCS with road vehicles will be necessary for the development of autonomous (road and rail) vehicles.

During 2021, CD company contacted me to try to work out a concept study of the BEMU 70 vehicle that could replace the RegioNova vehicle. The requirement was to design a two-way vehicle with a transport capacity of 74 seats that meets the requirements of CSN EN 12 663 in the P2 category and CSN EN 15 227 in the C I category and TSI PRM.

The result of this study is the design of the four-axle, partially low-floor BEMU 74 vehicle, see Figures 13 and 14.

The height of the edge of the floor in the boarding areas is 550 mm, and with the help of inclined ramps it changes to a height of 700 mm in the low-floor barrier-free section. In the interior above the bogies, the height of the floor is 940 mm. The basic components of the vehicle's traction equipment and auxiliary drives are comparable to the parameters used in metro vehicles. A comparison of the basic technical parameters of the vehicles is documented in Table 1.

In addition to operating on non-electrified regional lines, the BEMU 74 dual-power vehicle with a maximum output of 750 kW (640 kW for traction, 110 kW auxiliary drives) should be operable under 3 kV DC, 25 kV/50 Hz AC traction systems at a maximum speed of up to 120 km h^{-1}. The vehicle concept is shown in Figures 13 and 14.

With regard to the requirements of the "Green Deal" and significant use of recuperation, it is advisable that all wheel-sets will be driven, i.e. use a vehicle with a B_0' B_0' driving arrangement. Each wheel-set is driven by an asynchronous traction motor with a nominal power of 160 kW. The proposed electric AC power transmission will be powered by batteries (LTO) with a minimum capacity of 130 kWh on the shorter non-electrified sections of the track (range up to 50 km).

For longer non-electrified sections of the track,

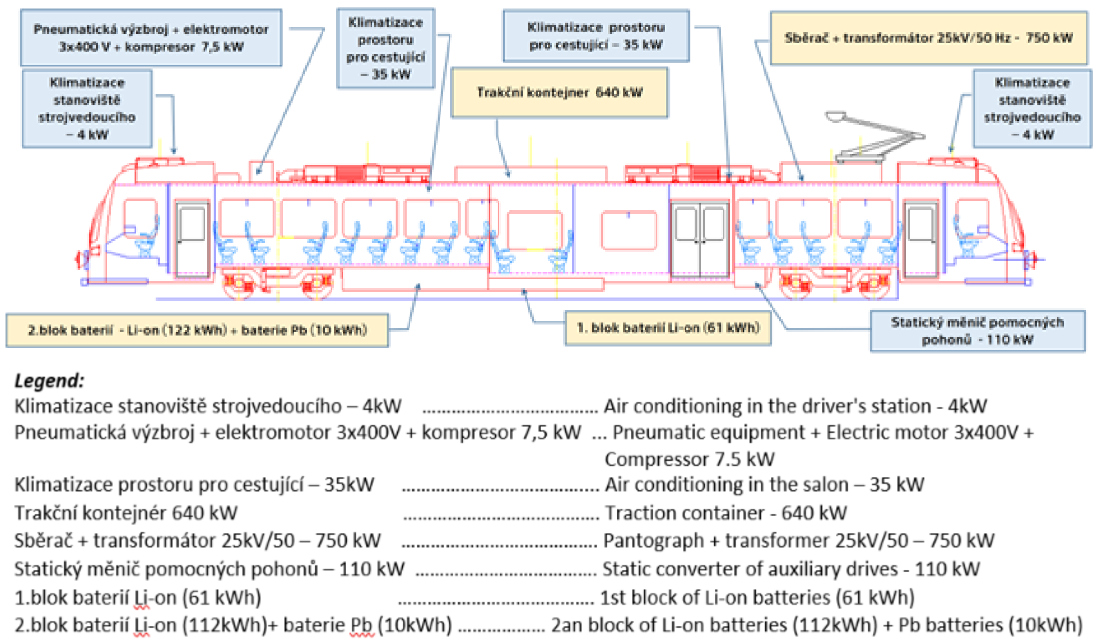

FIGURE 13. Concept of the BEMU 74 – Arrangement of electrical and pneumatic equipment for a two-power, three-system vehicle (AC 25 kV/50 Hz, DC 3 kV + battery).

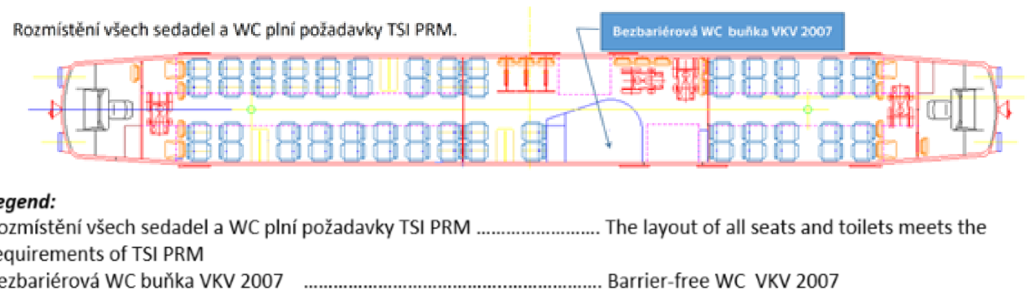

FIGURE 14. Concept of the BEMU 74 – Arrangement of the interior of the vehicle – space for immobile passengers.

	BEMU 74	**Regio Nove (814 + 914)**
Vehicle length over bumpers [mm]	25 750	28 440
Length of body vehicle [mm]	25 270	13 800 + 13 800 = 27 600
Width of the vehicle body [mm]	2 950	3 073
Number of fixed seats [–]	58	44 + 32
Number of folding seats [–]	16	8
Total seats [–]	74	84
Maximum number of passengers (fixed seats + 4 per. m^{-2}) [–]	**58 + 110 = 168**	**76 + 105 = 181**
Vehicle power [kW]	750	242 in 1 950 min^{-1}
Transmission of traction power	Electric drive	Hydromechanical
Service brake	Electrodynamic	Hyddrodynamic retarder + Pneumatic block brakes
Axle arrangement	$(a_0A_0)(A_0a_0)$ or B_0' B_0'	A'1' + 1'1'
Maximal speed [km h^{-1}]	120	80

TABLE 1. Comparison of basic vehicle parameters BEMU 74 and RegioNova.

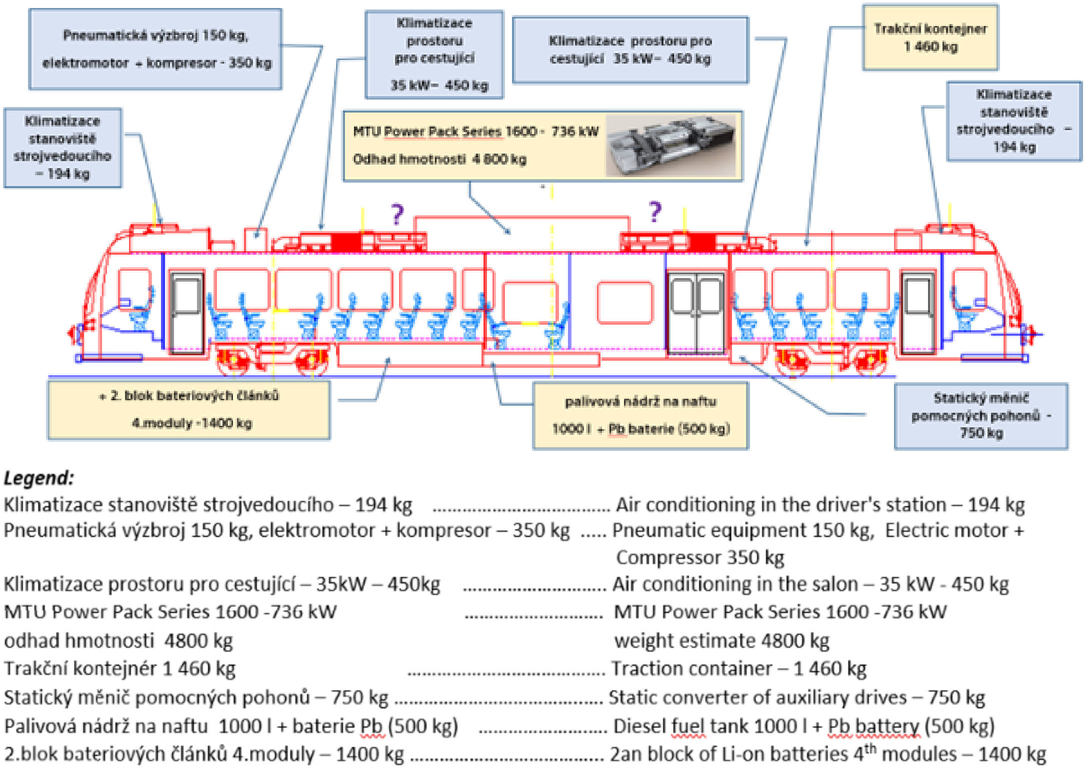

Figure 15. Concept of the HEMU 74 – Arrangement of electrical and pneumatic equipment.

where the energy stored in the battery power-pack (NMC) would not be sufficient, an alternative solution of the HEMU 74 vehicle is proposed, see Figure 15. Its basic drive unit located on the roof of the vehicle consists of an MTU Power Pack Series 1 600 – 736 kW diesel combustion engine with two alternators (for traction and auxiliary drives), see Figure 16, which could be modified to burn hydrogen.

For the HEMU 74 regional vehicle intended for more extensive operation on independent traction lines, it is more appropriate to use the concept of a hybrid vehicle (ICE + Aku) burning (biogas or hydrogen), as this type of hybrid drive can be better adapted to dynamic operational requirements. The indirect coupling of the ICE with the traction wheel allows the ICE to work in an optimal mode of operational consumption. The coverage of energy peaks during the moving off will and acceleration of vehicle ensure consumption from the accumulators.

A hybrid vehicle with a fuel hydrogens modules (HyPM HD 180) and electrical accumulators (Li-on) represents greater costs for the fuel modules HyPM (platinum design), which needs very clean hydrogen. The fuel hydrogen modules operate as a stationary source, it is poorly regulated (it does not tolerate dynamic changes in the operating load), it cannot recover electrical energy and must be supplemented with a more capacitive accumulator with a super-capacitator.

The solution of the interior and the rough structure of the car-body for both variants of the BEMU 74 and HEMU 74 vehicles is the same.

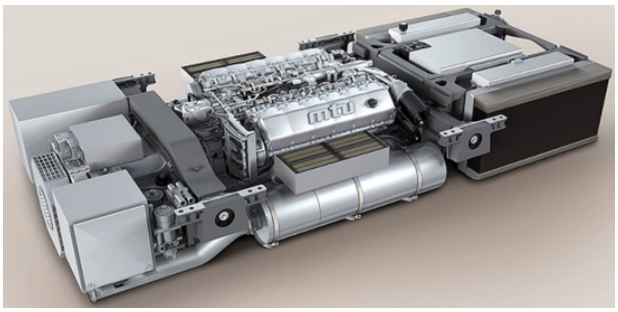

Figure 16. MTU Power Pack Series 1600 [15].

The ecological benefits of the proposed solution can be seen in the application of the operating electro-dynamic brake (EDB) and recuperation, which will reduce not only the energy demand for the driving cycle and therefore the price of fuel, but also ensure the minimal use of friction brakes only for braking and securing the vehicle, thereby significantly reducing dust and vehicle noise. From the performed traction calculations of an idealized driving cycle in a straight horizontal track on a track of 2 470 m, it emerged that 35 to 40 % of energy consumption can be saved by applying recuperation.

Acknowledgements

This research has been realized using the support of The Technology Agency of the Czech Republic, programme National Competence Centres, project #TN01000026 Josef Bozek National Center of Competence for Surface Transport Vehicles This support is gratefully acknowledged.

Furthermore, the paper presents the results of my partial with CD company.

References

[1] idnes.cz. [2022-05-05], https://www.idnes.cz/technet/technika/vlaky-doprava-kolejove-autobusy-lokalky-motoraky-hurvinek.

[2] cdnostalgie.cz. [2022-05-05], https://www.cdnostalgie.cz/vozidla/motorove-vozy/-32488/.

[3] J. Kolář. Konstrukční studie částečně nízkopodlažního kolejového autobusu s hybridním pohonem. In *PRORAIL 2015 – XXII. Medzinárodná konferencia Súčasné problémy v koľajových vozidlách – Zborník prednášok Diel I*, pp. 267–274. 2015. Žilinská univerzita, Strojnická fakulta, Žilina.

[4] railtech.com. [2021-07-27], https://www.railtech.com/rolling-stock/2021/07/27/taxirail-future-for-regional-rail/.

[5] railtech.com. [2022-05-05], https://www.railjournal.com/fleet/french-partnership-to-develop-light-autonomous-train/.

[6] railjournal.com. [2021-07-27], https://www.railjournal.com/fleet/french-partnership-to-develop-light-autonomous-train/.

[7] raulbus.com. [2022-05-05], https://railbus.com/vehicles/.

[8] transportdesigninternational.com. [2022-05-05], https://transportdesigninternational.com/portfolio/coventry-vlr.

[9] skodagroup.com. [2022-05-05], https://www.skodagroup.com/cs/.

[10] M. Dynybyl. Studie proveditelnosti autonomního tramvajového vozidla s dvounápravovým pojezdem. DP 2020, U 12 120, FS ČVUT, 2020.

[11] C. Schindler. The Aachen Rail Shuttle ARS – Autonomous and energy self-sufficient feeder transport. *Journal of Rail Transport Planning & Management* **21**:100299, 2022. https://doi.org/10.1016/j.jrtpm.2022.100299

[12] transportdesigninternational.com. [2022-05-05], https://www.railway-technology.com/projects/revolution-vlr-demonstrator-vehicle.

[13] portal.cenia.cz. [2022-05-05], https://portal.cenia.cz/eiasea/download/U0VBX01aUDI3MEtfbmF2cmhfMzkzODQ4MjAxMTQyMDY5Njc0NS5wZGY/MZP270K_navrh.pdf.

[14] J. Kolář. Konstrukční studie částečně nízkopodlažního kolejového elektrobusu. In *Zborník prednášok I. – XXIV. Medzinárodná konferencia – Súčasné problémy v koľajových vozidlách*, pp. 317–324. VTS pri ŽU, Žilina, 2019.

[15] flickr.com. [2022-05-05], https://www.flickr.com/photos/rrpowersystems/29935774845.