Regional Rail Rolling Stock for the FutuRe

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Abstract. Regional railway lines with lower usage need to be renewed to make them economically and environmentally sustainable, and this is the aim of FutuRe – a project supported by the Europe's Rail Joint Undertaking. Research is being conducted in several areas, such as traffic management, train positioning, automatic train control, wayside assets, multimodal travel and the vehicle itself, with the propulsion system and running gear being key research areas.

FutuRe proposes that this regional train should have a lightweight body, possibly with sections made of composite, and two single-axle running gears with active wheelset steering for improved curving performance. It is further proposed that train should be battery-powered and that the braking energy should be fully recovered into the battery. A control command and signalling concept dedicated to regional lines without the need to be interoperable with mainlines is being developed, enabling full automation (GoA4 –driverless, no train crew onboard). The concept matches the European initiatives in satellite communications and federated data spaces.

FutuRe's Key Performance Indicators show that the proposed vehicle will have lower energy consumption, generate less noise, require less maintenance and reduce the need for operational personnel compared to the regional trains that the market offers today.

Keywords: Regional railway · Rolling stock · Lightweight design · Battery powered · Automatic train operation

1 Introduction

Regional railway lines are vital for connecting rural areas and supporting the main rail network. However, many have been abandoned in recent decades due to high operational and maintenance costs. With changing mobility needs, several countries, particularly Germany and France, are now reconsidering the revitalization of these routes [1].

Given the typically low passenger volumes on rural lines, financial pressures are considerable. Avoiding costly infrastructure upgrades, such as overhead electrification, is therefore essential. A sustainable, cost-effective strategy for both rolling stock and infrastructure is required. Addressing these challenges is the focus of FutuRe, Flagship Project 6 (FP6) of Europe's Rail Joint Undertaking.

© The Author(s) 2027
D. Esztergár-Kiss et al. (Eds.): TRAconference 2026, LNMOB, pp. 861–869, 2027.
https://doi.org/10.1007/978-3-032-37207-9_102

FutuRe has produced a state-of-the-art report on small regional trains [2]. Current vehicles are mostly based on modular multiple-unit families. The smallest sustainable options for non-electrified branch lines are often two-car units, approximately 42–45 m long, with Jacobs bogies and around 120 seats for example, Siemens' Mireo Plus B and the Stadler Flirt Akku. From 2024, Stadler is also offering a single-car, two-bogie version powered by battery or hydrogen [3].

Innovative initiatives have developed even smaller zero-emission vehicles, such as TELLi in France and the Aachen Rail Shuttle in Germany [2, 4].

To keep regional railways economically viable, socially beneficial, and environmentally sustainable while meeting modern mobility demands, it is crucial to identify suitable vehicle concepts, propulsion technologies, and signalling systems. This paper presents the status of FutuRe developments and evaluates them against key performance indicators: energy consumption, exterior noise, and maintenance and personnel costs compared with existing regional trains.

2 Lightweight Body

Building a vehicle with low energy consumption, low acquisition and maintenance costs, and high sustainability requires trade-offs, especially for structural components like the car body and running gear frames. Materials must offer high mass-specific strength for lightweight construction, be easy to source and process, affordable, sustainable, and simple to dispose of. Manufacturing methods must be fast, scalable, low in energy use and CO_2 emissions, reliable, and produce minimal waste. Components must be easy to manufacture, assemble, maintain, and repair, while remaining durable and lightweight. Many of these requirements conflict, some materials enable lighter designs but are more expensive or require complex production, and developing durable lightweight components increases development time and cost.

To balance these factors, the FutuRe vehicle's car body development considers two construction methods to better address this complex challenge.

The first approach aims to minimize manufacturing and end-of-life cost and environmental impact. It uses welded steel frame structures for the load-carrying elements. With topology optimization guiding material distribution, this method still offers strong lightweight potential while relying on common, inexpensive manufacturing processes and an easily sourced, sustainable material [5].

The second focuses on maximizing weight reduction through a composite sandwich structure for the vehicle body. This design promises greater mass savings but requires more expensive materials, more complex production, and more challenging disposal. It also enables functional integration, such as noise and thermal insulation, which can further reduce weight. Lower mass reduces operational energy consumption and CO_2 emissions, potentially offsetting the higher manufacturing impact, since most of a train's environmental footprint occurs during its operational life [6].

To decide on the best solution, two car body structures using the two construction methods are developed in parallel. The complete designs are then analysed with respect to their overall cost and environmental impact over their whole product life.

In addition to those construction methods, a combination of both is also considered. The steel design is well suited for highly, localized load introduction, as occurs in the

running gear interfaces and at the vehicle front during crash. Sandwich structures excel at providing high stiffness on bigger surfaces while having low mass. A hybrid structure could potentially combine both construction methods in a multi material design approach where each material is used in the area where it can best utilize its advantages. Highly loaded areas like the running gear and crash absorber interfaces can be realized with a strong steel frame while the more uniform and lightly loaded middle sections can be realized with the lighter composite structures. For this, a reliable and easy to realize connection method has to be found to keep costs low. Also, this combination of materials requires a more complex manufacturing process and disposal tends to be more difficult. Further analysis is necessary to examine, whether the increased effort is offset by lower weight. A possible design for such a hybrid structure is shown in Fig. 1. It has topology optimized welded steel frames at the car ends and a sandwich structure in the middle.

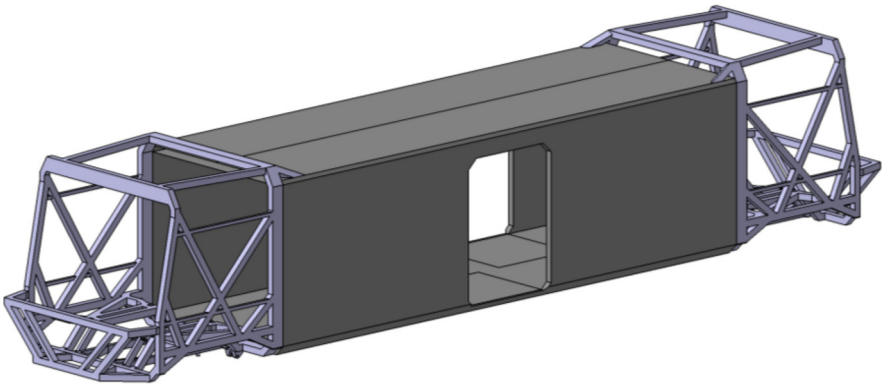


Fig. 1. Hybrid carbody structure, centre part in composite and ends in topology optimized steel.

3 Single-Axle Running Gear

Single-axle running gears have been used in rail vehicles since the first days of railway operation. They have primarily been applied in freight transport, where acquisition cost has typically outweighed performance requirements. These running gears are simple, lightweight, compact, and cost-effective compared to conventional bogies. For small regional vehicles, single-axle running gears enable the incorporation of a large low-floor area, making level boarding possible. Two different running gear concepts are developed and investigated, one with independently rotating wheels enabling the low floor section to extend throughout the entire vehicle, and one conventional wheelset design with an axle between the wheels. Single-axle running gear typically suffers from poor ride comfort and curving performance. In the concept with independently rotating wheels Fig. 2, a two-stage suspension improves the ride comfort, while curving is enhanced by individually controlling the traction motors to steer the wheels within the track channel. In the axle-based concept, both deficiencies are addressed via electrodynamic active control, as also proposed in Shift2Rail's Run2Rail project [7, 8]. It also enables a vehicle design without compressed air, using a simple coil spring for passive suspension.

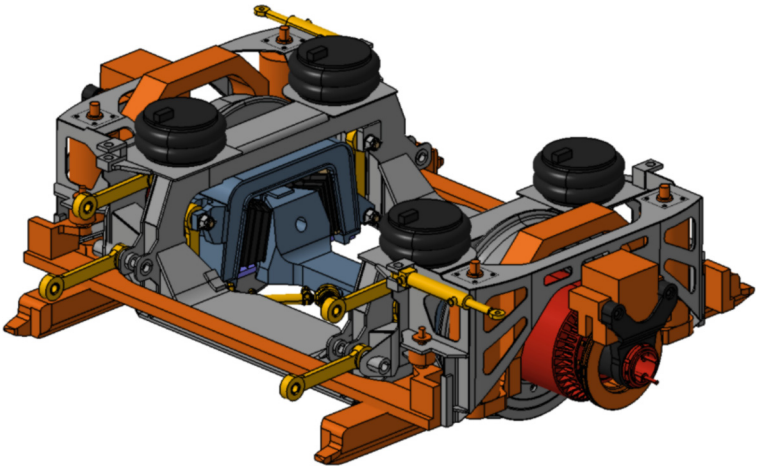


Fig. 2. Running gear with independently driven rotating wheels.

4 Battery Propulsion

Most low-density rail lines are not electrified, and since zero emissions at the vehicle level is a prerequisite, batteries have become the preferred energy storage solution. However, depending on the intended service, the distance between available charging opportunities can pose a challenge. Today's battery-powered trains typically have a shorter range between charges compared to battery-electric road buses. This is partly due to the higher operating speeds of rail vehicles, which lead to greater running resistance, and partly due to their significantly higher weight. Advancements in battery technology are essential for enhancing the performance, range, and sustainability of electric rail vehicles, developments that are largely being driven by the rapid progress in the electric road vehicle sector, [2, 9].

Adopting solutions from road vehicles has the potential to significantly reduce the weight and cost of the propulsion system. The planned propulsion power of 2 x 195 kW in the developed vehicle with conventional running gears is comparable to that of electric road buses, making the rail vehicle market attractive to suppliers from the road transport sector. In addition to the battery, the main components of the propulsion system are the inverters and traction motors, which could also be sourced from road vehicle suppliers. One key requirement is that all kinetic energy must be fully recovered to the battery during braking (emergency braking excluded). While this reduces the energy consumption and maintenance costs, but it results in high charging power levels, which can potentially reduce the battery's lifespan.

The maximum allowed axle load and available space for equipment limits the size of the battery package and thereby the possible distance between charging stations. Range extension can be achieved using hydrogen, which provides a lighter form of storage for large amounts of energy. The stored hydrogen must be converted into electrical energy, either via fuel cells or through hydrogen combustion. As total weight and space are limited, the hydrogen tanks and associated conversion systems would replace part of

the battery system. However, producing hydrogen and converting it to electrical energy is less efficient than using electrical power directly. Therefore, this solution should be evaluated in relation to the alternative of installing additional charging stations.

5 Signalling Concept

The used and adapted Control-Command and Signalling (CCS) low density lines architecture in FutuRe is based on four main inter-related building blocks which can be decomposed from an Operational, Functional and System point of view as seen in Fig. 3 [10].

The building blocks are	
Traffic Management and Control Centre	Communication data network
On-board equipment	Wayside equipment

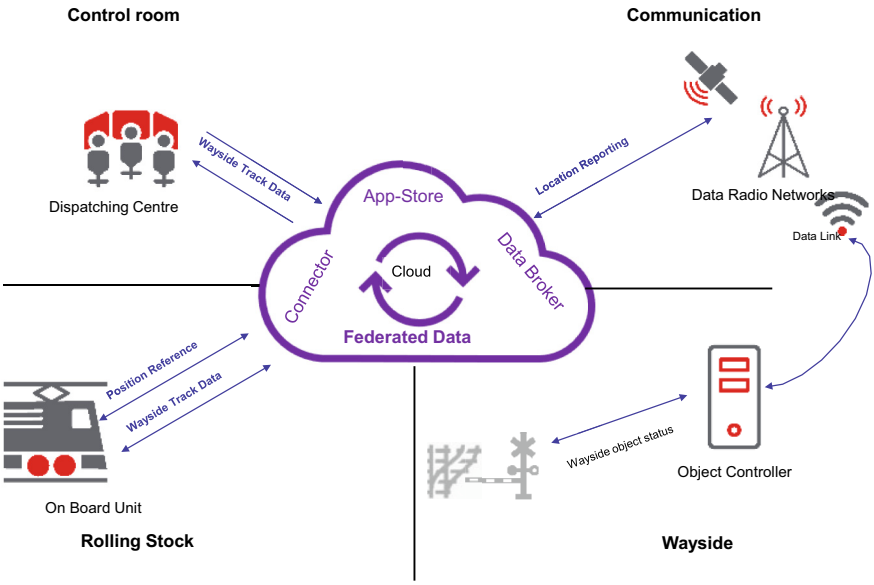


Fig. 3. Low density lines high level CCS architecture

On-board assembly of the CCS low density lines architecture uses the well-known concept of Communication Based Train Control (CBTC), with which positioning based on radio communication technologies can now be integrated. Modern train control solutions are generally radio based (such as various CBTC systems for automatic metros, railways using ERTMS Level 2 and Positive Train Control). Information among traffic control rooms, trains and wayside elements is exchanged wirelessly, using various

available communication means: public or private mobile networks and satellite communications. This approach allows optimisation of the data connectivity and utilisation of the EU based Federated Data Space while benefiting from the most performant and cost-efficient means.

In the proposed concept, radio and satellites provide train positioning data to the on-board unit (augmented for high precision, where required), which can use this to index an onboard digital track map (resulting from a standardized validation process), thus removing the need for wayside balises/transponders along the track. For safety reasons, to eliminate the need for high-cost track circuits and axle counters, the system requires the on-board unit to determine train length and train integrity.

Positioning technology performance is mature, currently to a precision of a few centimetres using satellites in conjunction with publicly available correction services. Soon, 6G & 7G will make localization cheaper and easier to implement (integrating cellular with satellite technology).

Such technologies will evolve more quickly than railway technology, and the CCS architecture must allow for this evolution, separately from the railway applications.

The CCS low density lines approach will enable the implementation of cost-effective, interoperable, fail-safe, highly accurate train positioning (including dead reckoning where required) based on data fusion of information from hybrid, multi sensor technologies, digital maps, onboard database.

This will not only increase operational efficiency and decrease Total Cost of Ownership in the context of regional lines, in addition, it will allow smooth adoption of higher grades of Automatic Train Operation (up to GoA 4), enabling driverless services on rural lines – a much-needed innovation that strengthens the competitiveness of regional rail.

6 Key Performance Indicators

The analysis compares four FutuRe-defined KPIs for resource efficiency between the proposed small regional vehicle and current market alternatives. The service plan assumes 16 daily trips in each direction, hourly from 6:00 to 21:00, with the smaller vehicle operating in multiple-unit formation for two morning and two afternoon peak services. The Swedish Gårdsjö–Håkantorp line (121 km, non-electrified) is used as an example. Its intermediate stops, gradients, and speed limits yield a simulated journey time of about 1 h 55 min including dwell times. The simulation accounts for system efficiency as a function of speed and power, as well as average auxiliary loads.

The energy consumption is simulated for peak and off-peak services as detailed in Table 1. The advantage of using smaller vehicles in off-peak are clear. The low weight and pure dynamic braking optimize the energy feedback to the battery. Furthermore, the FutuRe vehicle is designed for remote (automatic) driving, which optimizes the driving compared to what a driver can do, but this difference is not accounted for in the simulations. The average energy consumption reduction becomes 48%.

The remaining three KPIs focus on external noise emissions, maintenance costs, and personnel requirements. For a moving regional train, the primary source of external noise is the wheel-rail contact. Since the FutuRe vehicle has only two wheelsets compared to

Table 1. Simulated energy consumption

	Today's		FutuRe	
Service	Off-peak	Peak	Off-peak	Peak
Passengers per trip	20	60	20	2 x 30
Number of trips a day	28	4	28	4
Energy consumption per trip (kWh/km)	2.59	2.68	1.21	2.26

four on current vehicles, the sound energy is expected to be halved. This corresponds to a noise reduction of approximately 3 dB.

Put simply, maintenance costs for rail vehicles (and the infrastructure) are determined by the number of wheelsets multiplied by the kilometres travelled, assuming the axle load is about the same. Today's vehicles produce 32 trips * 121 km * 4 wheelsets = 15488 wheelset km a day, while the FutuRe vehicle produces 36 * 121 * 2 = 8712 wheelset km, corresponding to a reduction of 44%.

The smaller vehicle is assumed to be operated fully automatic (GoA4) with a remote train control as a backup option. This reduces the personnel demand significantly, as today a train driver in each vehicle is needed (Table 2).

Table 2. KPI summary

Property	Influence
Energy consumption	−48%
External noise emission	-3 dB
Maintenance	−44%
Personnel	−80%

7 Conclusion

The development of the regional vehicle introduces a new system design for low-density lines, combining modern approaches that improve competitiveness in rural areas by reducing vehicle CAPEX and OPEX, control-command equipment needs, and overall system maintenance. The vehicle targets non-electrified lines, using a lightweight car body and innovative running-gear concepts to enable a flat low-floor interior, ensuring seamless boarding and independent PRM access.

A battery-based power pack is central to the design, balancing capacity with required range. Energy management optimises overall consumption, including HVAC, and recovers braking energy. The vehicles will operate within a highly automated traffic management and train control framework, requiring minimal trackside infrastructure while meeting performance targets.

Despite progress, further development is needed within upcoming Europe's Rail Joint Undertaking projects. Physical demonstrators of key subsystems are planned for 2028, followed by full vehicle testing under future EU flagship initiatives.

Acknowledgements. Funded by the European Union. Views and opinion expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Europe's Rail Joint Undertaking. Neither the European Union nor the granting authority can be held responsible for them. The Flagship project 6 FutuRe is supported by the Europe's Rail Joint Undertaking and its members

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