Regional Rail Rolling Stock for the FutuRe

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FP6-FutuRe Cost effective regional lines

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.

Given the typically low passenger volumes on rural lines, financial pressures are considerable. Avoiding costly infrastructure upgrades, such as overhead electrification and/or trackside signalling, 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.

FutuRe has produced a state-of-the-art report on small regional trains. 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. Most can be ordered with various traction systems, including overhead, battery, hydrogen, or diesel. From 2024, Stadler is also offering a single-car, two-bogie version powered by battery or hydrogen.

Recent innovative initiatives have developed even smaller zero-emission vehicles, such as TELLi in France and the Aachen Rail Shuttle in Germany.

To keep regional railways economically viable, socially beneficial, and environ-mentally sustainable while meeting modern mobility demands, it is crucial to identify suitable vehicle concepts, propulsion technologies, signalling and automation 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 trains.

Lightweight body

Designing a vehicle with low energy use, low acquisition and maintenance costs, and high sustainability requires balancing conflicting demands, especially for structural components like the car body and running gear frames. Materials must combine high mass-specific strength, affordability, sustainability, ease of processing, and simple disposal. Manufacturing must be fast, scalable, low-energy, low-emission, reliable, and produce minimal waste. Components must remain durable and lightweight while being easy to build, assemble, maintain, and repair. Many requirements conflict: lighter materials may be costly or complex to produce, and developing durable lightweight parts increases time and expense.

To address this, the FutuRe vehicle's car body development evaluates two construction methods. The first minimizes manufacturing and end-of-life cost and environmental impact by using welded steel frame structures for load-carrying elements. With topology optimization guiding material distribution, this approach still offers strong lightweight potential while relying on inexpensive, widely available steel.

The second aims for maximum weight reduction using a composite sandwich structure. This promises greater weight savings and better functional integration, such as noise and thermal insulation, though with higher material and manufacturing costs and more difficult disposal. Lower operational energy use and CO_2 emissions may offset the higher production impact, since most of a train's environmental footprint occurs during operation.

Both structures are developed in parallel and assessed for life-cycle cost and environmental impact. A hybrid solution is also considered: steel frames for highly loaded areas such as running gear interfaces and crash zones, and sandwich structures for the lighter, more uniform middle sections. This could combine the strengths of both materials, though it requires reliable, low-cost joining methods and involves more complex manufacturing and disposal. Further analysis is needed to determine whether weight savings justify the added effort. Figure 1 shows a possible hybrid design with topology-optimized steel ends and a sandwich middle section.

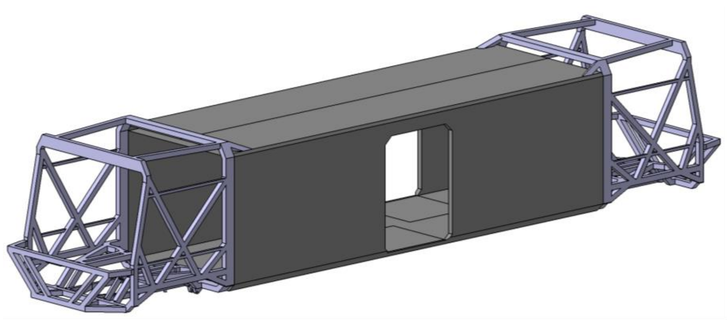


Figure 1 Carbody concept in steel sandwich hybrid.

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 to reduce acquisition costs. 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 Figure 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. It also enables a vehicle design without compressed air, using a simple coil spring for passive suspension.

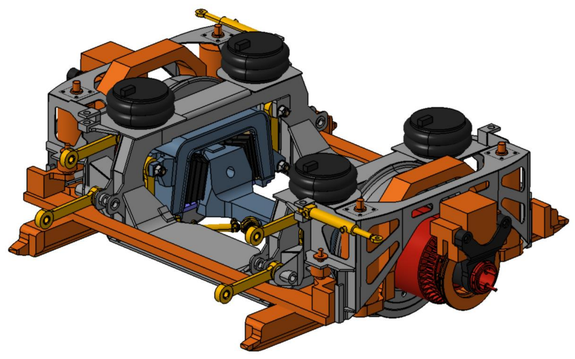


Figure 2: Running gear with independently rotating wheels

Signaling concept

The Control Command and Signalling (CCS) low-density lines architecture in FutuRe is built on four interconnected building blocks, viewed from operational, functional, and system perspectives (Figure 3).

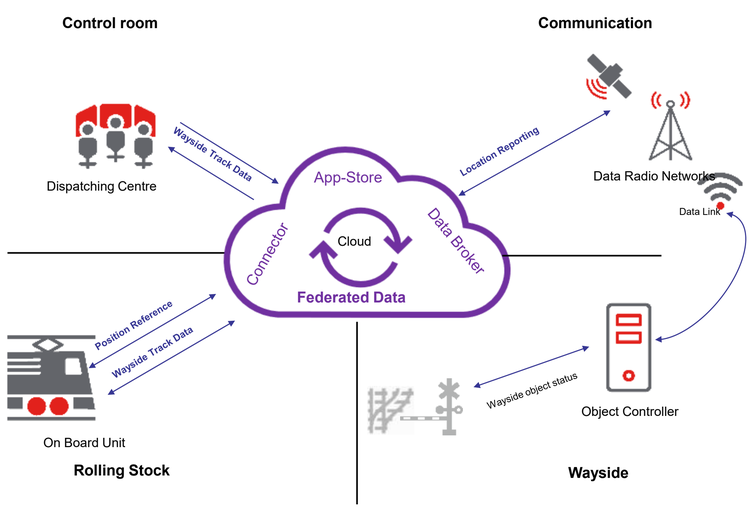


Figure 3: CCS architecture for low-density lines

The proposed concept of CCS low-density lines architecture uses Communication-Based Train Control (CBTC), exchanging data wirelessly between control room, trains, and wayside elements via public or private mobile networks and satellites. This enables optimized connectivity and use of the EU Federated Data Space with cost-efficient communication.

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. 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, thus the CCS architecture must allow for this evolution, separately from the railway applications.

This approach enables cost-effective, fail-safe, highly accurate positioning, using data fusion from hybrid sensors, digital maps, and onboard databases, including dead reckoning. It improves operational efficiency, reduces total cost of ownership, and supports higher grades of Automatic Train Operation (up to GoA4), enabling driverless services on rural lines and strengthening regional rail competitiveness.

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. 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.

Adopting road-vehicle solutions can greatly reduce propulsion system weight and cost. The planned 2 × 195 kW power is similar to electric buses, making rail applications attractive to road-sector suppliers. Besides the battery, inverters and traction motors could also be sourced from them. A key requirement is full recovery of kinetic energy during braking (except emergencies). This lowers energy use and maintenance but demands high charging power, which may shorten battery life. Axle-load limits and available installation space restrict battery size and therefore the distance between charging stations. Hydrogen can extend range by providing lighter storage for large energy quantities. It must be converted to electricity via fuel cells or combustion, replacing part of the battery system. However, producing and converting hydrogen is less efficient than direct electric use, so this option must be weighed against installing additional charging stations.

Key performance indicators

The assessment compares four FutuRe KPIs on resource efficiency for a small regional vehicle against current market vehicles. The service plan assumes 16 daily trips per direction, hourly from 6:00 to 21:00. The Swedish Gårdsjö–Håkantorp line (121 km, non-electrified) is used as an example. Including gradients, stops, and speed limits, the simulated journey time is about 1 h 55 min.

The smaller vehicles shows clear benefits on energy consumption: low mass and full dynamic braking maximize energy recovery. The vehicle size also positively influence external noise and maintenance cost.

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. The KPIs are summarized in Table 1.

Table 1. KPI summary

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

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