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Cost efficient regional rolling stock

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Regional railway lines are vital for rural connectivity, but many have been closed due to high operating and maintenance costs. As mobility needs change, countries such as Germany and France are reconsidering their revival. Because passenger volumes are low, expensive upgrades like overhead electrification are unrealistic, making affordable and sustainable vehicle and infrastructure solutions essential.

The FutuRe project (Europe's Rail JU, Flagship Project 6) develops vehicle concepts, propulsion systems, and signalling tailored to low-density lines, targeting a train smaller than today's two-car, 120-seat regional units. Designs prioritise lightweight construction and cost efficiency, exploring both optimized welded steel carbodies and composite sandwich structures. Running gear innovations include single-axle systems with independently rotating wheels or solid axles with electrodynamic active steering.

Propulsion is battery-based, using automotive components to reduce cost and weight, with optional range extension via extra batteries or hydrogen. A new CBTC-based signalling architecture using radio, satellite positioning, and digital maps enables cost-effective, fail-safe train control and supports automation up to GoA4.

5.1 Introduction

Regional railway lines are vital for connecting rural areas and supporting the wider rail network. However, many such lines have been abandoned in recent decades due to high operational and maintenance costs. As mobility needs evolve, several countries, particularly Germany and France, are now reconsidering the revitalization of these routes [1]. Because passenger volumes on rural lines are typically low, financial pressures are significant. Avoiding costly infrastructure upgrades, such as overhead electrification, is therefore essential, making sustainable and cost-effective solutions for both rolling stock and infrastructure a key priority. Addressing these challenges is the focus of FutuRe, Flagship Project 6 (FP6) of Europe's Rail Joint Undertaking.

FutuRe first reviewed the state of the art in small regional trains [2]. Most current vehicles are derived from modular multiple-unit platforms, with the smallest zero-emission solutions for non-electrified branch lines typically being two-car units 42–45 m long, using Jacobs bogies and providing around 120 seats, such as Siemens' Mireo Plus B and Stadler's Flirt Akku. More recently, Stadler introduced a smaller single-car, four-axle battery- or hydrogen-powered variant. Other initiatives, including France's TELLi and Germany's Aachen Rail Shuttle, further demonstrate growing interest in highly compact, low-cost, zero-emission rail vehicles.

To support the long-term economic, social, and environmental sustainability of low-density regional railways, further development of dedicated vehicle concepts, propulsion systems, and signalling solutions is needed. This paper presents the current status of the FutuRe project, [3].

5.2 Lightweight carbody

Developing a rail vehicle with low energy use, low cost, and high sustainability requires balancing competing requirements for materials, manufacturing, and structural design. Materials should be lightweight, strong, affordable, sustainable, and easy to process and recycle, while manufacturing should be efficient, scalable, reliable, and low in environmental impact [4]. Because lightweight solutions can increase cost and complexity, the FutuRe project evaluates two car body concepts in parallel.

The first uses a topology-optimized welded steel frame, aiming to minimize manufacturing cost and environmental impact while retaining good lightweight performance using available, sustainable materials and conventional production methods. The second employs a composite sandwich structure to maximize weight reduction. Although this approach involves higher material, production, and disposal costs, it enables functional integration

such as thermal and acoustic insulation and can reduce operational energy consumption and emissions. To identify the optimal solution, both concepts are developed and assessed across their full life cycle for cost and environmental performance [5], Figure 1 and Table 1. In addition to those construction methods, a hybrid structure of both is also considered combining both construction methods in a multi material design approach where each material is used in the area where it can best utilize its advantages.

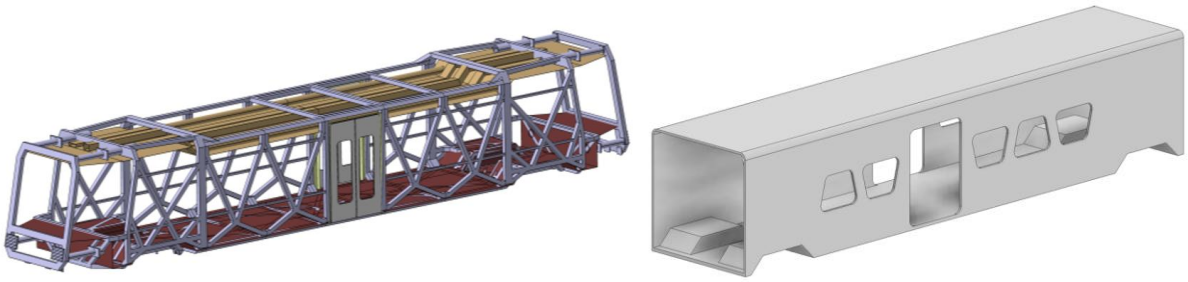


Figure 1: Topology optimized steel carbody (left), sandwich composite carbody (right) [3]

Property	Topology optimized steel carbody	Sandwich composite carbody
Manufacturing	Medium	Complex
Weight	Medium	Low
Handling concentrated loads	Good	Poor
Thermal insulation	Poor	Good
Reparability	Good	Complex
Recyclability	Good	Complex

Table 1: Property comparison: topology optimized steel vs. sandwich composite

5.3 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, 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 [6]. It also enables a vehicle design without compressed air, using a simple coil spring for passive suspension, Figure 2 and Table 2.

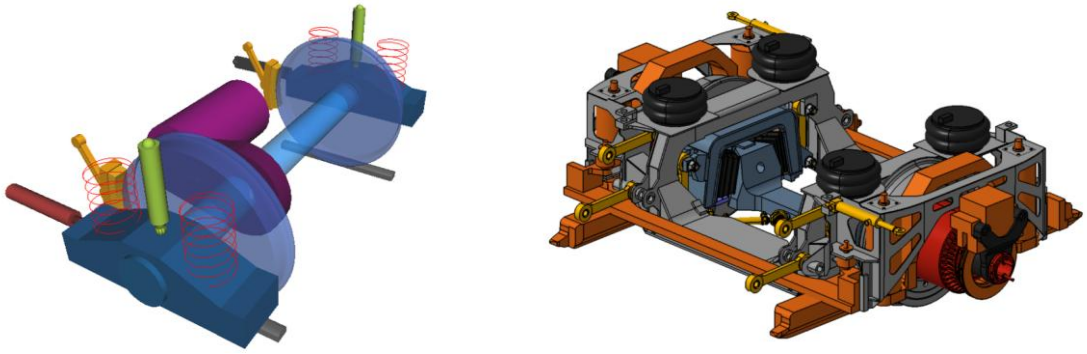


Figure 2: Running gear, solid axle (left), independently driven rotating wheels (right),[3]

Property	Conventional design	Independently driven rotating wheels	Bogie (reference)
Manufacturing	Simple but dynamic active elements needed	Complex	Simple
Weight	2100 kg	3300 kg	6000 kg
Suspension step	1 (Dynamic active elements needed)	2	2
Traction motor	From road suppliers	Dedicated design	Conventional
Support 100% low floor	No	Yes	No
Support compressed air free vehicle	Yes	No	No

Table 2: Property comparison: single-axle conventional vs. independently driven rotating wheels and bogie as reference

5.4 Battery propulsion

Most low-density rail lines are not electrified, and since achieving zero emissions at the vehicle 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 than battery-electric road buses. This is partly due to the higher operating speeds of rail vehicles, which increase running resistance, and partly due to their greater mass. Advancements in battery technology are essential for improving the performance of electric rail vehicles developments that are largely being driven by rapid progress in the electric road-vehicle sector [2][3].

Adopting solutions from road vehicles has the potential to significantly reduce the weight and cost of the propulsion system. The planned propulsion power of 390 kW, distributed

across two or four motors, is comparable to that of electric road buses, making it feasible to source propulsion components from road-vehicle suppliers.

The maximum permitted axle load and the available installation space limit the size of the battery pack. Batteries also have notable environmental drawbacks due to resource-intensive production and polluting extraction processes. Consequently, the vehicle should not be equipped with larger batteries than necessary for the intended service. The base vehicle includes a battery sized to absorb the high regenerative braking power, but with a range limitation of approximately 200 km depending on service conditions, Figure 3.

The vehicle has three anticipated options for propulsion and energy supply: an additional battery, a high-voltage AC/DC charger enabling charging from catenary, and a hydrogen-based range extender using fuel cells (FC) or internal combustions engine (ICE).

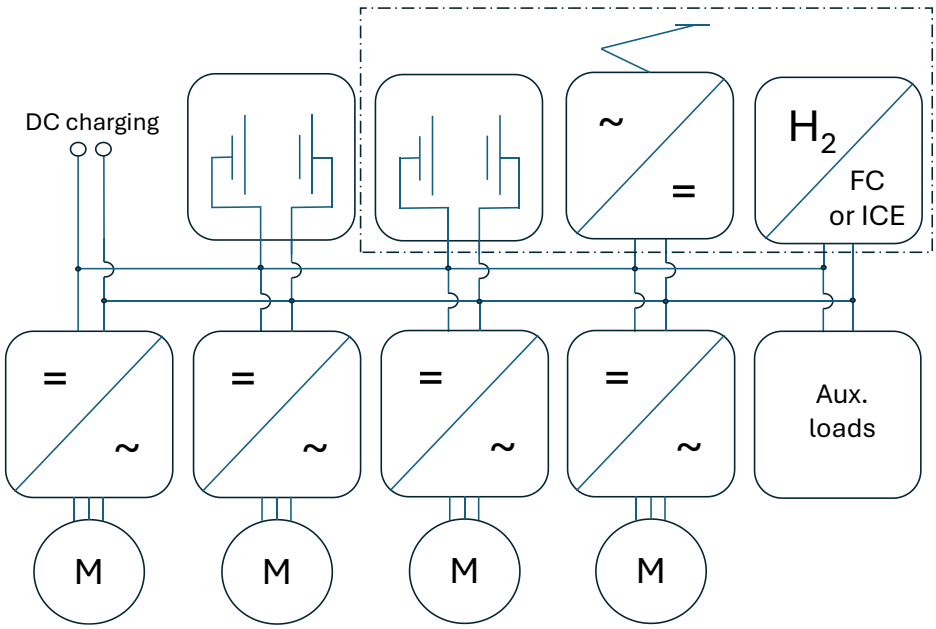


Figure 3: Proposed propulsion architecture (dotted line = options)

5.5 Signalling concept

Two approaches have been developed by the FutuRe project to address the traffic management, Control-Command and Signalling (CCS) on low density lines:

a. The target architecture, minimising the extent of trackside equipment and thus drastically saving both capital and operation costs
b. The interim / migration solution, enabling to cope with the existing trackside signalling and train protection system, allowing also to ensure compatibility for transit services to and from mainline of required so

5.5.1 The target architecture

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 be integrated. 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, Figure 4.

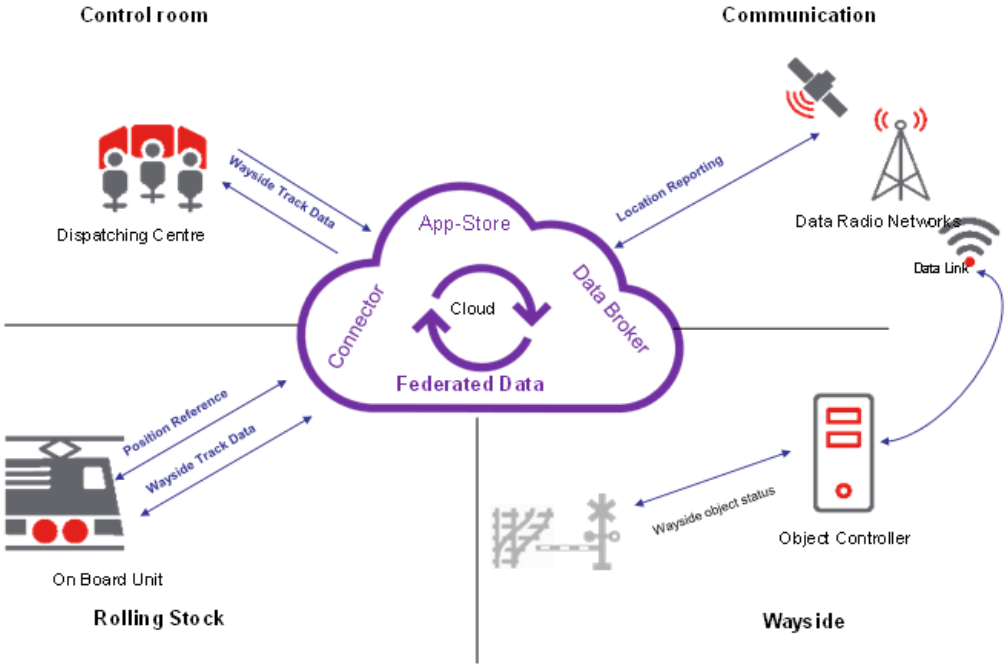


Figure 4: Target CCS architecture for low density lines [7]

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 pro-cess), 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. This novel CCS architecture 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.

5.5.2 Interim cost-efficient CCS migration scheme

VirtuoSig® is a digital signalling solution that emulates conventional trackside signalling and operating rules while remaining fully compatible with existing ATP systems.

Trackside, it replaces lateral signals and train detection equipment such as track circuits and axle counters. Block sections and train separation rules are managed digitally through a vital central traffic control system that combines dispatching and interlocking functions.

Onboard, it delivers digital ATP codes directly to existing ATP equipment while preserving full compatibility with legacy systems. Trains can therefore revert to conventional operation when required, ensuring operational continuity and supporting phased deployment in mixed-technology environments.

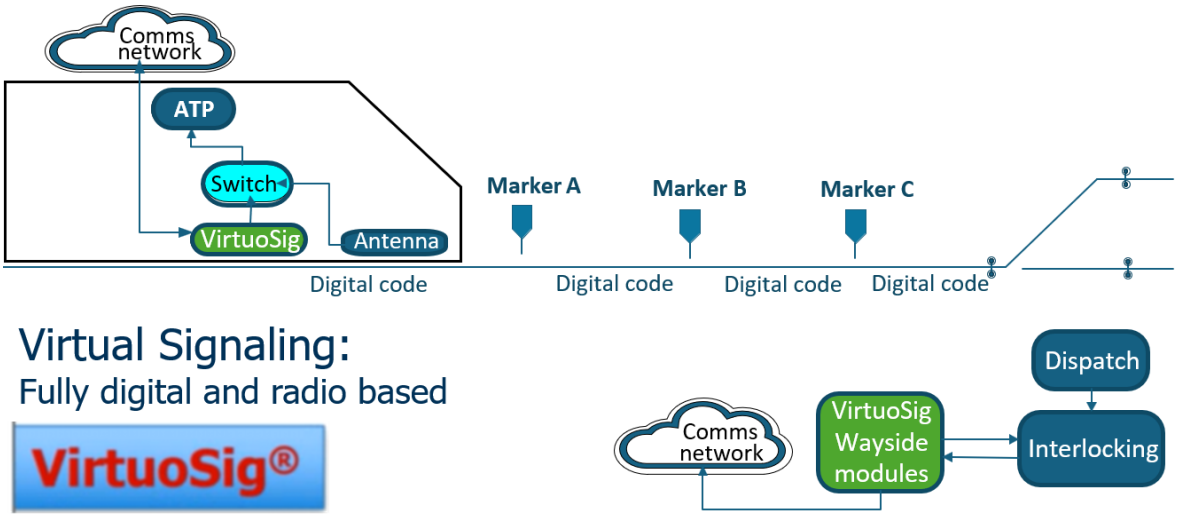


Figure 5: Architecture for the interim solution

The interim solution changes only the method by which ATP codes are transmitted; existing signalling principles and operating rules remain unchanged. Hence it enables infrastructure managers to upgrade regional and especially low-density lines at software speed, reuse what works, and create a clear, low-risk migration path that unlocks efficiency and capacity gains while preparing fleets and infrastructure for the target signalling solution.

5.6 Summary

FutuRe (Europe's Rail FP6) aims to revitalize low-density regional railways through cost-effective, zero-emission vehicles and low-cost signalling solutions. The project addresses the economic challenges of rural rail services by developing a lightweight, energy-efficient train tailored to non-electrified branch lines.

Two carbody concepts, a topology-optimized steel structure and a composite sandwich design are being evaluated for their life-cycle cost and environmental performance. To maximize accessibility and interior space, two innovative single-axle running gear concepts are also under development.

Battery-electric propulsion forms the basis of the vehicle, with options for additional batteries, catenary charging, or hydrogen-based range extenders. To reduce cost and weight, the propulsion system leverages technologies from the electric road vehicle sector.

For signalling, FutuRe proposes a train control architecture with satellite and radio positioning, minimizing trackside equipment and enabling future automation. As an interim solution, a system that digitally reproduces conventional signalling while remaining compatible with existing train protection systems, providing a low-risk migration path for regional railways.

Acknowledgements

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