Proceedings of the Seventh International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 15, Paper 23.7
Civil-Comp Press, Edinburgh, United Kingdom, 2026
ISSN: 2753-3239, doi: 10.4203/ccc.15.23.7

Alternative Drive Systems in Regional Rail: Roles, Interfaces, and Technical Dependencies

B. Ebrecht and U. Zimmermann

Chair of Railway Operations and Infrastructure, Technische Universität Berlin, Germany

Abstract

This paper presents a structured assessment of battery-electric and hydrogen multiple unit fleet introductions in German regional rail networks, covering 31 projects in operation or under procurement as of early 2026. A research database compiled from public tender notices, operator announcements, and expert exchanges forms the empirical basis.

The analysis examines four dimensions: procurement and financing models, timescales from vehicle order to commissioning, charging infrastructure provision, and recurring operational challenges. The analysis reveals systematic patterns in planning timelines, recurring causes of commissioning delays, and structural differences between the two dominant procurement models. Delayed vehicle delivery and unsynchronised charging infrastructure were identified as the most frequent causes of commissioning delays across all networks examined.

Two principal procurement models are compared using unified modelling language use case and sequence diagrams: authority-managed fleet pools and operator-procured vehicles. The structural differences in interface complexity, risk allocation, and scalability are discussed.

The paper concludes that battery-electric traction introduction is a multi-dimensional optimisation problem with no universal solution, and derives recommendations for procurement planning, infrastructure coordination, and stakeholder responsibilities.

Keywords: alternative traction, battery train, fleet procurement, regional rail, operational experience, stakeholder analysis, systems modelling

1 Introduction

Local rail transport in Germany is undergoing a transformation in terms of propulsion technology. A four-digit number of diesel railcars is in service – a large portion of which operate on routes that are not or only partly electrified for economic or technical reasons and will not be electrified in the foreseeable future. Hydrogen and battery-electric multiple units (HEMU and BEMU) are viewed in political and technical discussions as a key tool for replacing this fleet and achieving climate targets in regional rail transport.

Since the first fleet was put into service in August 2022 on the “Nasses Dreieck” network (Lower Saxony), the number of operations currently underway and in preparation using alternative propulsion systems has increased significantly. In practice, however, these rollouts are often fraught with challenges: vehicle deliveries are delayed, charging infrastructure is not available in time, and established processes from conventional vehicle procurement are only partially applicable.

This paper provides a structured overview of ongoing and planned BEMU service launches in Germany and derives insights that can serve as a basis for action for public transport authorities, rail operators, and other stakeholders. Particular focus is placed on the vehicle procurement models, the timelines from order to service launch, and recurring problem areas.

2 Background

The introduction of vehicle fleets with alternative propulsion systems and their entry into service encounter established structures in the awarding of transport services and the procurement of vehicles. These are already diverse in the status quo and structured according to the political strategies of the respective federal states. The “classic” model still exists, whereby transportation contracts are awarded to rail transport companies (RTCs), which subsequently handle vehicle procurement themselves and also arrange the corresponding financing. In doing so, they rely on the one hand on financial support from the federal states or public authorities, and on the other hand increasingly on external companies that specialize in vehicle financing. [1]

In recent years, another model has emerged in which the public transport authorities themselves handle the procurement and financing of the vehicles and subsequently make the vehicles available to the rail operators for the operation of the acquired regional rail networks. These models, in turn, are divided into various approaches regarding exactly how financing is structured or who is responsible for the various levels of maintenance, for example, the operating rail carrier or the vehicle manufacturer itself. Examples of this include the RRX model of the Rhine-Ruhr Transport Association (VRR) or the vehicle pool of the Lower Saxony State Local Transport Company, which has been in existence since 1997. [2][3]

All these models have been and continue to be accompanied by the establishment of ever-new interfaces, which in turn raise further questions regarding risk allocation and the incentive structures of the individual stakeholders. The increase in the number of stakeholders alone results in a greater need for coordination. The stakeholders can be broadly divided into public and private entities, although private companies under public ownership can certainly act as private stakeholders, as is the case with DB Regio or the Southwestern German Railway Company (SWEG).

Continuing with the example of Germany, *Table 1* provides an overview of the stakeholders involved, although it should be noted that

- depending on the characteristics of the regional rail network to be operated, not all stakeholders need to be involved.
- a single stakeholder may combine multiple roles. While there are, of course, some guidelines regarding responsibilities, this is not the case for all tasks.

Stakeholder	Task
State (Federal Republic of Germany)	Creates legal regulations and financing instruments for railways in general and regional rail transport in particular (e.g., public services pursuant to the Basic Law or the Passenger Transportation Act (PBefG))
Federal states	Receive so-called regionalization funds from the federal government for regional rail transport and decide on the use of these funds; Responsible for financing regional infrastructure (can be co-funded by the state)
Responsible transport authorities (TA)	Often state-owned entities that take on the direct organization of regional rail transport (e.g., network planning, timetable planning, tendering, awarding contracts)
Railway transport companies (RTCs)	Carry out train operations, including planning (unless otherwise specified by the responsible authority); may also be responsible for the maintenance of railway vehicles,
Railway infrastructure companies (RIC)	Operate and maintain railway infrastructure; also expand infrastructure on behalf of the state (e.g., catenary isles)
Rail vehicle manufacturers	Design and manufacture regional rail vehicles (electric multiple units or locomotive-hauled trains) according to tender specifications; may also be responsible for the maintenance of railway vehicles,
Suppliers of individual vehicle components, who may in turn have their own suppliers (tier suppliers)	Design and manufacture individual components for rail vehicles, such as battery modules, in accordance with vehicle manufacturers' specifications; in turn, they may use suppliers for items such as battery cells as needed.
Builders of charging infrastructure or H_2 refueling stations	Plan and construct infrastructure for charging/refueling vehicles with alternative propulsion systems on behalf of government agencies or RIC/RTC
Operators of charging infrastructure or hydrogen refueling stations	Operate infrastructure for charging/refueling vehicles with alternative propulsion systems

Electricity supplier or hydrogen supplier	Provide power or hydrogen for railway operations.
Rail vehicle financiers	Procure rail vehicles and lease them to railway operators; financing models for RTC or TA when they are procuring vehicles themselves

Table 1: Stakeholders within German regional train operation

Due to the technological characteristics of BEMU/HEMU vehicles, the number of stakeholders increases further. (see Figure *1*) On the one hand, additional suppliers of vehicle components such as batteries come into play; on the other hand, in many cases, charging/refueling infrastructure must be planned and constructed along the rail infrastructure, which in turn requires manufacturers and operators. Furthermore, the already crucial coordination among stakeholders regarding technical and operational alignment becomes even more important, as the challenges – particularly in BEMU operations with significantly limited range – substantially increase the number of available solutions. Thus, the limitation of range in operation can often be addressed with multiple solutions (adjustment of turnaround times, adapted route network and scheduling, larger traction batteries, additional vehicles), which involve very different stakeholders and are funded from different sources.

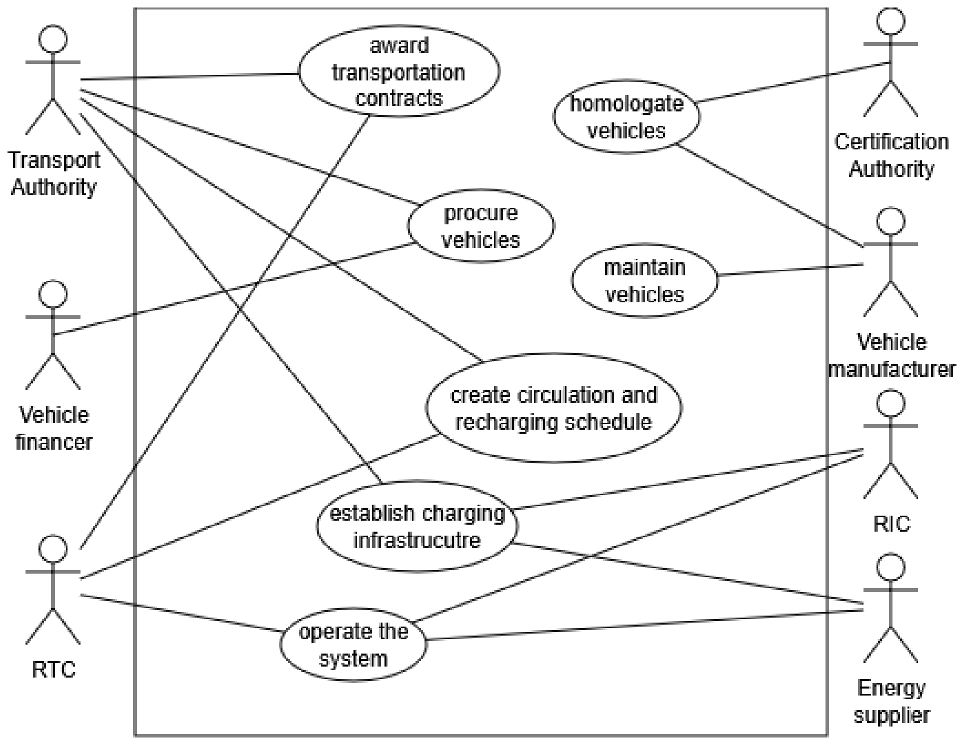

Figure 1: Use case diagram for the commissioning of a BEMU train based on the AT-Pool model.

Analysis

For this study, 31 projects in German regional rail transport were analyzed in which vehicles with alternative propulsion systems (BEMU or HEMU) are in use or whose deployment is specifically planned. *Table 2* provides an overview. The dataset comprises 26 BEMU networks and 5 HEMU projects; it thus largely covers the operations currently underway or planned in Germany. It should be noted that, depending on the focus of the analysis, not all projects are included, and results may vary, as, for example, not all data is publicly available or delays in future commissioning dates have not yet been definitively determined.

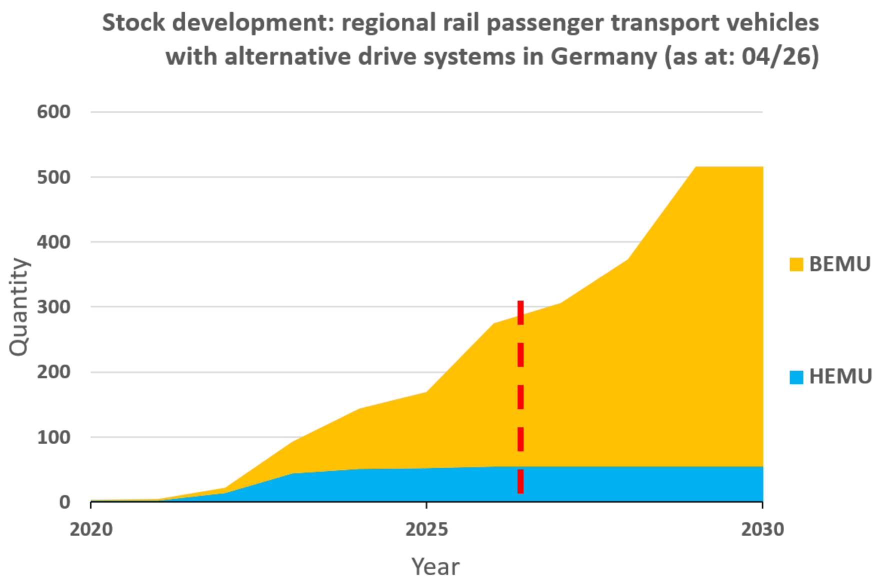

Figure 2: Development of the fleet rollout for BEMU and HEMU trains in Germany, with an outlook on future service launches.

Following initial pilot operations of demonstrator vehicles using both propulsion technologies, the first fleet-scale launch of a HEMU network took place in the summer of 2022 by EVB (Eisenbahnen und Verkehrsbetriebe Elbe-Weser) on the “Nasses Dreieck” in Lower Saxony. The first BEMU fleet started launching in 2023 with 55 vehicles across 3 sub-networks in Schleswig-Holstein. Figure *2* shows the timeline of service launches from 2022 through the planning horizon of 2030. [4][5][6]

<table>
<thead>
<tr><th>Network</th><th>Federal State</th><th>Number of lines / lines using BEMU / HEMU</th><th>Mio. BEMU/ HEMU-Train-Km Per Year</th><th>Number of BEMU (B) / HEMU (H)</th><th>Procurem ent model</th></tr>
</thead>
<tbody>
<tr><td>Nord / Ost / Ost-West</td><td>SH</td><td>11 / 11</td><td>10.4</td><td>55 (B)</td><td>AT-Pool</td></tr>
<tr><td>Ortenau</td><td>BW</td><td>5 / 5</td><td>2.3</td><td>24 (B)</td><td>AT-Pool</td></tr>
<tr><td>Hermann-Hesse-Bahn</td><td>BW</td><td>1 / 1</td><td>0.36</td><td>3 (B)</td><td>AT-Pool</td></tr>
<tr><td>Chemnitz-Leipzig</td><td>SN</td><td>1 / 1</td><td>1.1</td><td>11 (B)</td><td>AT-Pool</td></tr>
<tr><td>Niederrhein-Münsterland - Teilnetz 1</td><td>NRW</td><td>2 / 2</td><td>6.7</td><td rowspan="2">66 (B)</td><td rowspan="2">AT-Pool</td></tr>
<tr><td>Niederrhein-Münsterland - Teilnetz 2</td><td>NRW</td><td>6 / 6</td><td>4</td></tr>
<tr><td>Nördliches Westfalen Los 1</td><td>NRW</td><td>2 / 2</td><td>0.3</td><td>10 (B)</td><td>AT-Pool</td></tr>
<tr><td>Nördliches Westfalen Los 2</td><td>NRW</td><td>8 / 8</td><td>7.1</td><td>61 (B)</td><td>Leasing (for AT-Pool)</td></tr>
<tr><td>Warnow Los 2</td><td>MV</td><td>8 / 3</td><td>2.2</td><td>19 (B)</td><td>RTC</td></tr>
<tr><td>Westmecklenburg</td><td>MV</td><td>4 / 4</td><td>2.2</td><td>14 (B)</td><td>RTC</td></tr>
<tr><td>Ostbrandenburg</td><td>BRB</td><td>9 / 8</td><td>5.6</td><td>31 (B)</td><td>RTC</td></tr>
<tr><td>MAN - Mittelthüringer Akkuzugnetz</td><td>TH</td><td>8 / 8</td><td>3.5</td><td>19 (B)</td><td>RTC</td></tr>
<tr><td>Nasses Dreieck</td><td>NDS</td><td>1 / 1</td><td>1.3</td><td>14 (H)</td><td>AT-Pool</td></tr>
<tr><td>Heidekrautbahn</td><td>BRB</td><td>1 / 1</td><td>0.76</td><td>7 (H)</td><td>RTC</td></tr>
<tr><td>Pfalznetz</td><td>RLP</td><td>8 / 8</td><td>4.6</td><td>44 (B)</td><td>RTC</td></tr>
<tr><td>Eifel-Westerwald-Sieg (Los 2)</td><td>RLP</td><td>7 / 4</td><td>0.4</td><td>3 (B)</td><td>RTC</td></tr>
<tr><td>Taunus</td><td>HS</td><td>4 / 4</td><td>2.5</td><td>27 (H)</td><td>AT-Pool</td></tr>
<tr><td>Linienstern Mühldorf</td><td>BY</td><td>13 / 1</td><td>0.45</td><td>3 (H)</td><td>RTC</td></tr>
<tr><td>MDSB2025+</td><td>SN</td><td>4 / 1</td><td>1.56</td><td>16 (B)</td><td>AT-Pool</td></tr>
<tr><td>Tesla-Shuttle</td><td>BRB</td><td>1 / 1</td><td>0.15</td><td>3 (B)</td><td>Leasing</td></tr>
<tr><td>RE47</td><td>NRW</td><td>1 / 1</td><td>0.5</td><td>3 (B)</td><td>Leasing</td></tr>
<tr><td>Neigetechnik Nordostbayern</td><td>BY</td><td>10 / 10</td><td>n/a</td><td>n/a (B)</td><td>RTC</td></tr>
<tr><td>Neigetechnik Allgäu</td><td>BY</td><td>5 / 5</td><td>n/a</td><td>31 + x (B)</td><td>RTC</td></tr>
<tr><td>Elektronetz Saar</td><td>SL</td><td>4 / 1</td><td>0.51</td><td>6 (B)</td><td>RTC</td></tr>
<tr><td>Ländechsbahn</td><td>HS</td><td>1 / 1</td><td>0.06</td><td>1 (B)</td><td>Leasing</td></tr>
</tbody>
</table>

Table 2: Selected networks from the research database, showing key fleet procurement data.

3 Methods

Methodologically, this study is divided into data collection, data preparation, and the formalization and derivation of schemas.

Data Collection

The data basis for the study is a research database compiled by the team of authors on the introduction of BEMU and HEMU trains into German regional rail transport. The data was compiled from publicly available sources, including tender notices (TED), press releases from transport authorities and manufacturers, publications in trade and daily media (including public broadcasters and local press), and conference presentations.

For each network, the database records, among other things: the public transport authority and railway operator, vehicle type and number, procurement model, various timestamps of key events (tender, award, planned commissioning, actual commissioning), type and scope of the charging infrastructure, as well as documented delays and problems. The completeness of the data is not guaranteed for all parameters; in particular, cost data is available for only a portion of the networks. This circumstance must be taken into account in the evaluation algorithms with regard to statistical methods and cross-references.

A similar analysis has been carried out for identifying the boundary conditions for BEMU/HEMU implementation, aggregating all diesel operated regional lines in Germany.

Breakdown of Interests

The structural links between the stakeholders presented in Chapter 2 are diverse in nature. Foremost among these are the financial links, which primarily stem from the financing of vehicles, operations, and infrastructure. Regional public transport in Germany is largely financed and organized directly by the federal government and the federal states, and the funding mechanisms are structured accordingly. These include, on the one hand, regionalization funds or funds from the Municipal Transport Financing Act (Gemeindeverkehrsfinanzierungsgesetz GVFG), with the former primarily intended for the procurement of transport services (which may also include vehicle procurement), while the latter are intended for the construction and expansion of transport infrastructure. [7] In parallel, various funding programs have been launched that focus on both vehicles and infrastructure for alternative propulsion systems. [8]

In addition to financial aspects, stakeholders are closely linked in the areas of operations and technology. In part, this reflects the existing situation, driven by the necessity to offer a highly integrated system with multiple points of contact, despite the division of tasks among several stakeholders. New types of infrastructure are necessary to ensure the vehicles' energy supply. These new vehicles have high energy requirements while stationary for charging their traction batteries, which in some cases requires separate infrastructure in the form of charging stations or overhead line isles. Similarly, hydrogen refueling stations are a technology not yet widely deployed in the railway sector.

The limited range of BEMU vehicles, in particular, in turn requires operational adjustments to ensure, for example, the necessary charging times. All planning considerations must be integrated and summarized early in the commissioning phase of new regional rail networks, as many decisions can have an impact on other areas. Vehicle battery sizes must be coordinated with the placement of the charging infrastructure; route and rotation planning must take into account the recharging capacity determined by the vehicle and infrastructure, as this significantly determines how quickly vehicles can be sent back to non-electrified sections of track.

The interconnections mentioned in the previous section are not always optimally reflected in German regional rail transport. A central planning authority with an overview of the entire system is only available to a limited extent through the responsible authorities. Public knowledge exchange also occurs only partially, and data-based analyses have been rare to date. In addition, different stakeholders come into play at different times; in some cases, decisions affecting their domain have already been made without sufficient coordination being planned. Details can be found in chapter 4.

SWOT Analysis

The SWOT analysis, as a structured tool for evaluating a subject of study by distinguishing between factors that can be controlled internally and external conditions, is suitable for synthesizing diverse individual findings into a clear overall picture and for deriving recommendations for action. This SWOT analysis was developed based on the research database described above and supplementary expert assessments. The authors assigned the individual findings to the four categories by comparing them with documented operational experience from the networks under study. The subject of the study is examined here from a macroeconomic perspective; in other words, the SWOT analysis reflects the overall "BEMU Commissioning" system—not the perspectives of individual stakeholders.

Formalization of processes

To structure the relationships and interactions described above, key processes within the BEMU/HEMU commissioning system are formalized using Unified Modelling Language (UML). A use case diagram maps the principal stakeholders and their involvement in the main system functions (Figure *1*). Sequence diagrams additionally trace the vehicle procurement process for the AT-Pool and RTC models respectively, making differences in decision pathways, interface complexity, and risk allocation directly comparable (Figure *4*).

4 Results

The results include projects with a volume of 100 million train-kilometers per year, covering approximately 45% of regional rail services that were still diesel-powered in 2019. While the first networks were tendered as technology-neutral – with the procurement decision ultimately resulting in battery-electric vehicles in each case – the propulsion technology is now generally specified by the transport authority at the time of tendering. The research shows that the technology decision in Germany has largely been made in favor of the BEMU.

SWOT Analysis

Table *3* summarizes the results of the SWOT analysis. Compatibility with existing rail infrastructure emerges as a structural strength of the overall system: unlike electrification, no major track-side modifications are required. This is offset by a key weakness: the inability to standardize operational concepts – each network requires individual optimization of range, charging infrastructure, and route planning.

	+ Positive	- Negative
Internal (controllable)	Strengths (S) • Achieving climate goals by reducing local emissions • Increased comfort for passengers • Manufacturer maintenance contracts provide an incentive for low-maintenance technology implementation • AT pool models lower market barriers • Experience from pilot operations, demonstration vehicles, and initial fleet operations is available	Weaknesses (W) • Range limitation as a new limiting factor in operational planning • Complex tender planning with the longest lead time for necessary charging infrastructure • No coordinated transfer of know-how between fleet operations • Complex network of interfaces: TA, RTC, RIC, manufacturers, energy suppliers, maintenance providers
External (uncontrollable)	Opportunities (O) • Potential for new route connections that were not possible with diesel trains • Vehicle technology available on the market across manufacturers • Increasing battery energy density improves range in the long term without the need for infrastructure expansion • Progress in standardization (EN 50119, charging standards) reduces technical uncertainty • TCO: Advantages over diesel operation due to predictably lower	Risks (T) • Frequent delays in commissioning and contingency plans place a burden on the entire regional rail network • Responsibility for infrastructure is not defined, which in some cases hinders technical innovation • Charging infrastructure: regulatory gaps and partly dependency on fixed operators (no competition!) • No state- or federal-level coordination of charging infrastructure placement and sizing

	operating costs and independence from rising CO_2 costs • Extensive subsidy programs (GVFG, Development bank, federal funds) partially cover additional costs	• Funding programs not permanently secured – funding gaps possible after expiration • Approval procedures remain a bottleneck

Table 3: SWOT Analysis of BEMU/HEMU's introduction into the German regional public rail transport market with replacement of diesel trains from a broad economic perspective.

On the positive side, government subsidy programs serve as a key enabler: without GVFG funding and state grants, the charging infrastructure would not have been economically viable in any of the networks examined. The greatest structural risk lies in the oligopolistic position of a few vehicle manufacturers: delivery delays by a single manufacturer affect multiple networks simultaneously due to the close timing of tenders.

Timelines and lead times

An analysis of the lead times between vehicle award and planned commissioning reveals a range of 27 to 89 months for the networks analyzed, with a range of approximately 40 to 55 months (excluding special leasing cases such as the Tesla shuttle). This corresponds to an average planning lead time of approximately 3.5 to 4.5 years. Figure *3* illustrates the lead times of one network exemplary.

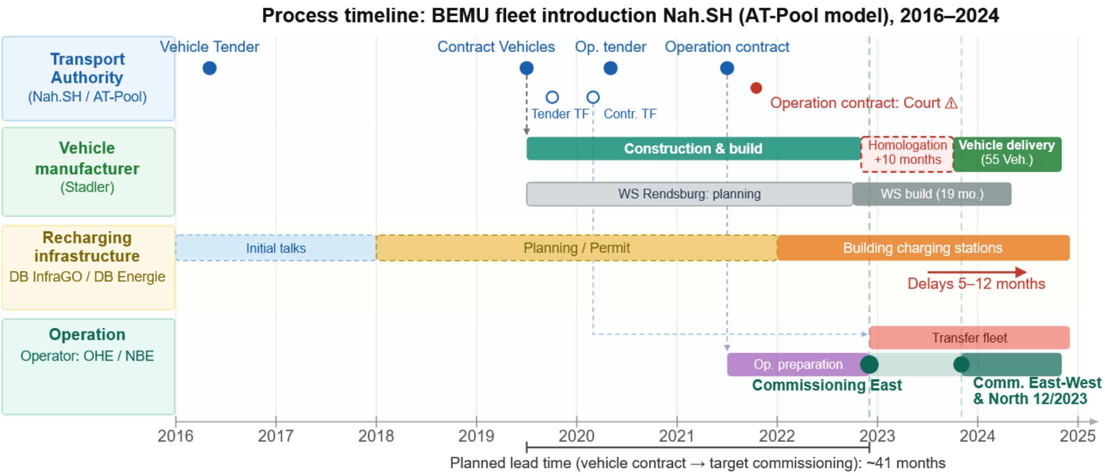

Figure 3: Exemplary lead times for the German Nah.SH BEMU network.

Compared to conventional diesel multiple units (DMU) procurements, this range is comparable; however, it is evident that actual commissioning dates in the majority of networks fell behind the target dates. In most cases, delivery delays occur with both drive technologies. The choice of procurement model has no apparent impact on whether these delays occur. The most common cause is the delayed delivery of vehicles—in several cases by more than 12 months—followed by delays in the charging infrastructure.

Identification of Problem Areas

The issue of switching from BEMU to EMU mode (and vice versa), which must be performed at the beginning or end of overhead-wire-free sections, appears to be the most significant problem to date. The regulations assign sole responsibility to the train driver based on signals permanently mounted along the track (mostly metal signs). However, in several BEMU networks of the German regional rail network, there have been numerous incidents in which the switch was forgotten or performed at the wrong time, resulting in damage to the vehicle or the overhead contact line system. [9] Although rail vehicle manufacturers are currently developing assistance systems to support train crews, the question remains whether, given the frequency of these incidents, automating this mode change would be advisable.

In isolated cases, lowered pantographs have frozen to the roof. As far as is known, this has occurred under specific weather conditions such as freezing rain and does not represent a general problem in winter. Nevertheless, due to the novelty of the technology, there is still a lack of robust data across various winter conditions. When stationary, this is often counteracted by regularly raising and lowering the pantograph, but this is not possible during operation while traveling in BEMU mode.

General problems with vehicle range have not yet occurred on German regional rail networks. Even though there are no public evaluations on this yet, the assumptions made in planning and design regarding energy buffers in traction batteries appear to have been on the conservative side, so it can be assumed that, taking into account several years of operational experience, the buffers may be designed smaller in the future to avoid maintaining oversized vehicle fleets. No negative effects have yet been observed regarding the service life of traction batteries; initial assessments even suggest a longer service life than planned. However, there is still far too little experience available for a valid assessment.

Other recurring problem areas can be identified across the analyzed networks:

- **Vehicle delivery delays**: Nearly all networks already in operation experienced delays in the delivery of new vehicles, often due to registration issues, supply chain problems with traction batteries, or rework resulting from last-minute changes to vehicle specifications (e.g., CAF Civity BEMU, retrofitting for 400V charging). In almost all cases, this necessitated the use of transfer fleets, the quality and availability of which varied greatly. [10]
- **Infrastructure synchronization**: None of the networks examined fully succeeded in providing charging infrastructure on schedule in parallel with vehicle delivery. In Schleswig-Holstein (Nah.SH), individual charging stations were 5-12 months behind schedule, meaning that vehicles had to be operated with a limited range of use at times.

• **Registration procedures**: Unforeseen delays in the registration process occurred for several vehicle types. In the North/East/OS-West network (Nah.SH), registration was delayed by approximately 10 months; in the Nasses Dreieck network, only 5 of the 14 ordered iLint vehicles were in service at the start of operations. [5][11]

Comparison of two procurement models

Flowcharts (sequence diagram of the vehicle procurement process) are used to illustrate the key differences in decision-making processes, interfaces, and risk allocation.

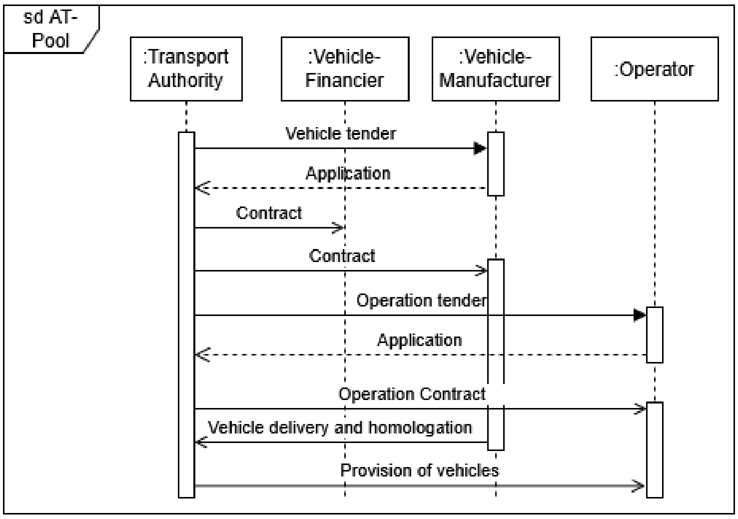

Figure 4: Sequence diagram of the AT-Pool procurement process.

The comparison shows that while the AT-Pool model (Figure *4*) involves a higher number of formal interfaces and greater coordination efforts, it offers more network-independent vehicle availability and better scalability. In the RTC model, business responsibility lies more heavily with the operating company, which can simplify processes but also increases dependence on the RTC's financial strength and risk profile.

A significant difference between the two vehicle procurement models is that, under the AT-Pool model, the transport authority is responsible for extensive coordination tasks. In contrast, the RTC has less ability to directly implement lessons learned from operational experience in this case. There is no direct contractual relationship between the vehicle manufacturer and the operator. This lack of a working foundation can lead to subsequent problems, for example, when newly identified challenges during operation must be addressed collaboratively. This particularly affects data exchange between the vehicle and the RTC, which can be used for dispatching purposes, among other things. It has been observed that this gap has not yet been addressed, or has been addressed inadequately, in Germany for BEMU/HEMU operations, which are expected to require more post-operation adjustments than conventional fleets.

Consequently, the recommended course of action is to ensure such activities from the outset through the organization of the Transport Authority.

5 Conclusions and Contributions

Operational data to date indicate that the rollout is well underway, yet far from complete, as the majority of the vehicles ordered have not entered revenue service. Observed project timelines suggest that lead times of four years or more constitute a realistic planning baseline and should therefore be incorporated as a minimum assumption in tendering processes. The implementation environment is further characterized by a “shared-responsibility” structure, in which a complex network of stakeholders assumes responsibility for different tasks, thereby increasing coordination requirements and system complexity.

At the same time, several critical aspects remain insufficiently addressed. In particular, fleet management within an integrated network—such as fleet management in a network (Connected Driver Assistance Systems) and cross-network dispatching—has received little attention to date, highlighting a clear need for further research. Moreover, the transferability of findings to other European railway systems is limited due to specific institutional and regulatory characteristics of the German context and competitive dynamics among operators. Nevertheless, certain structural insights, especially with regard to lead times and the synchronization of infrastructure and rolling stock deployment, remain broadly applicable.

The current data landscape presents a significant challenge. Systematic collection of both cost data and operational performance metrics is largely absent, and the overall availability of reliable, verifiable figures is notably poor. This situation is particularly problematic given the extensive use of public funding instruments, and it underscores the need for standardized and uniform reporting requirements for publicly funded BEMU/HEMU infrastructure. The lack of transparency also points to the importance of accompanying research; however, such efforts have repeatedly failed to materialize, in part due to the strong operational focus of rail operators during the ramp-up phase.

In addition, empirical evidence suggests that infrastructure costs are substantially higher than anticipated in earlier studies. Institutional arrangements may further exacerbate these challenges, as vehicle owners without prior railway experience – such as financial investors participating in asset pool (AT-Pool) models – often lack intrinsic incentives to contribute to the long-term development and optimization of the system. Against this backdrop, it is recommended that infrastructure planning processes commence no later than the point at which vehicles are ordered, as delays in this regard have proven to be a recurring issue in several cases.

References

[1] U Bitterberg, "Fahrzeuge für den SPNV in Deutschland. EVU- und Fahrzeugpool-Beschaffungsmodelle“, in Eisenbahntechnische Rundschau, Eurailpress-Verlag, 2023, no. 7+8, 72-76.

[2] R.R.F. Lünser, „Fahrzeugpool und neue Finanzierungsmodelle”, in Der Nachverkehr, Eurailpress-Verlag, 2020, no. 11, 11-14.

[3] C. Müller, „Der Fahrzeugpool ist ein sehr wirtschaftliches Modell“, in RailBusiness, Eurailpress-Verlag, 2011, no. 31, 9.

[4] P. Boev, B. Ebrecht, S. von Mach, U. Zimmermann, "First Passenger Operation of a State-of-the-art Battery-Electric Multiple Unit (BEMU) in Germany", in Transportation Research Procedia, Elsevier, Volume 72, 2023.

[5] C. Grimm, T. Nawrocki, „Erste Betriebserfahrungen mit Brennstoffzellenzügen“, 6. Eurailpress-Forum Alternative Antriebe im SPNV, presentation

[6] NAH.SH, „Die Ausschreibung der Akkunetze in Schleswig-Holstein“ [online] Available at: [https://akkuzug.nah.sh/] (accessed: 02nd April 2026)

[7] Bundesverband Schienennahverkehr, „Wie wird die SPNV-Infrastruktur bereitgestellt und finanziert?“ [online] Available at: [https://www.schienennahverkehr.de/spnv-erklart-wie-wird-die-spnv-infrastruktur-finanziert-und-bereitgestellt/] (accessed: 02nd April 2026)

[8] Bundesministerium für Verkehr, “Alternative Antriebe im Schienenverkehr“ [online] Available at [https://www.bmv.de/DE/Themen/Mobilitaet/Elektromobilitaet/Elektromobilitaet-im-schienenverkehr/elektromobilitaet-im-schienenverkehr.html] (accessed: 02nd April 2026)

[9] P. Meerkamp, „Akkuzüge beschädigen regelmäßig Oberleitungen“, in Der Tagesspiegel, [online] Available at [https://background.tagesspiegel.de/verkehr-und-smart-mobility/briefing/akkuzuege-beschaedigen-regelmaessig-oberleitungen] (accessed: 03rd April 2026)

[10] M. Brüning, „Realisierungsstand des BEMU-Projektes bei VRR und NWL“, 8. Eurailpress-Forum Alternative Antriebe im SPNV, presentation

[11] B. Schulze, „Erfahrungen aus der BEMU-Einführung in Schleswig-Holstein“, 7. Eurailpress-Forum Alternative Antriebe im SPNV, presentation