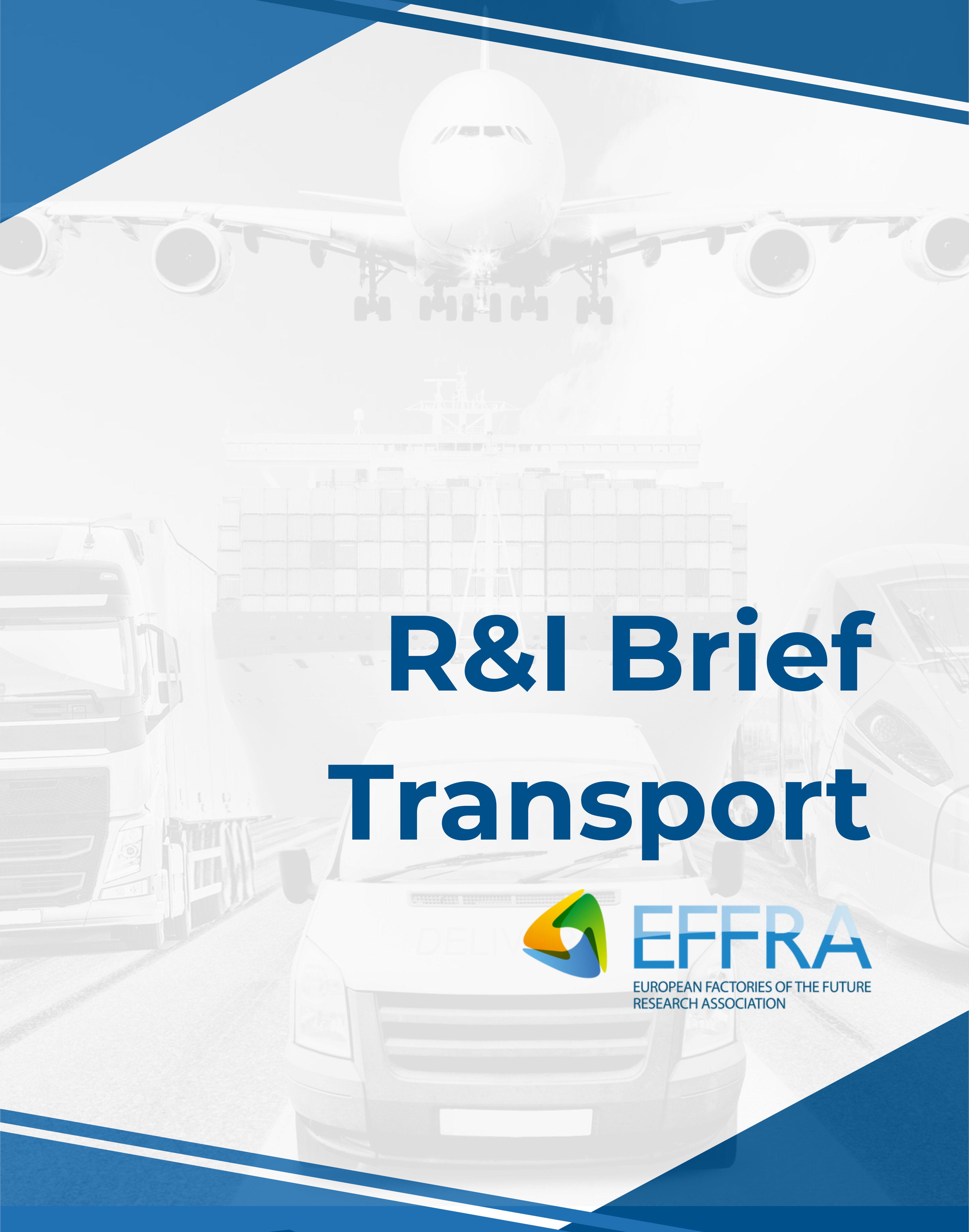

R&I Brief Transport

EFFRA
EUROPEAN FACTORIES OF THE FUTURE
RESEARCH ASSOCIATION

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1 Executive Summary

This policy brief, developed by the EFFRA Thematic Working Group on Transport, presents a comprehensive overview of the current state, challenges, and research and innovation (R&I) priorities in manufacturing for the transport sector. It aims to inform the European Commission and relevant stakeholders about the strategic directions needed to enhance Europe's competitiveness, sustainability, and technological leadership.

The brief synthesises EFFRA member inputs and visions towards Europe’s manufacturing industry of the future. Key recommendations include advancing digitalization, circular economy practices, skills development, and infrastructure modernisation to address pressing societal and industrial needs, focusing on:

- Innovative production methods and circular business models
- New materials and structures
- Circular design approaches
- Digitalisation in manufacturing
- Human-centric automation
- Work force development

2 Present State and Rationale

The European transport manufacturing sector is undergoing a profound transformation driven by digitalisation, sustainability imperatives, and global competition. Recent technological advancements, including digital twins, artificial intelligence, and additive manufacturing, are transforming production processes.

Policy frameworks like the EU Clean Industrial Deal and Fit for 55 are setting ambitious targets for decarbonisation and circularity, necessitating innovation across the value chain.

Despite these advances, significant gaps remain. The integration of digital technologies across distributed supply chains is uneven, and the scalability of sustainable manufacturing practices is limited. The European Union faces increasing competition from global players, particularly in Asia and USA, where the pace of innovation and industrial deployment is accelerating. Maintaining leadership in sectors such as aerospace, while catching up in automotive manufacturing, is critical for Europe's strategic autonomy.

3 Challenges and Needs

The relevance of manufacturing for transport extends beyond industrial competitiveness. It is central to achieving climate goals, international mobility, ensuring mobility equity between urban and rural areas, and fostering social acceptance of new mobility solutions. The sector's evolution must therefore be guided by a holistic approach that integrates sustainability, technological, industrial, and societal dimensions.

3.1 Sustainability

The transport manufacturing sector faces a multitude of challenges that span environmental, societal, technological, and economic dimensions. One of the most pressing concerns is the **carbon footprint** associated with the full automotive and aviation systems, encompassing emissions of vehicles in operation, parts production, and the transport of components across distributed supply chains. Addressing this issue requires a holistic approach that considers energy efficiency, local production strategies, and sustainable logistics, taking cross-sectoral fertilisation where possible.

Circularity in manufacturing is another area of concern, driven by both sustainability and strategic autonomy with respect to critical raw materials. Concepts like reverse factories and de-manufacturing ecosystems are gaining traction, but the lack of design-for-disassembly in current components, limited remanufacturing infrastructure, and regulatory uncertainty around the reuse of safety-critical parts pose significant barriers.

3.2 Technological

The development of fully autonomous vehicles and public transportation systems introduces **new manufacturing requirements** and safety considerations. Similarly, the railway sector faces challenges in reducing the cost of construction, maintenance, and operation, as well as in manufacturing new trains more efficiently.

Extended reality (XR) technologies are underutilized in training for transport manufacturing processes, despite their potential to enhance safety, precision, and adaptability. The absence of spatially contextualised XR guidance for remote diagnostics and maintenance, coupled with difficulties in interacting with complex digital twin data, limits their effectiveness.

The development of **novel high-performance materials** is opening new possibilities to develop lightweight and resistant components for transport. However, these materials cannot always be transformed using traditional techniques, so manufacturing technologies must evolve to be ready for using high-performance materials.

3.3 Industrial

The **competitiveness** of the European Union in automotive manufacturing is under pressure, particularly in comparison to the rapid evolution observed in China. Europe must take proactive steps to preserve and enhance its industrial edge across all transport sectors. For example, the strong position in aerospace manufacturing, exemplified by companies like Airbus, needs to be maintained when new products are developed for short-medium range and regional flights during the period 2028-2034, which covers a large part of the market, and for innovative air mobility.
Development of manufacturing capabilities is needed to allow sufficient scaling up to the requisite market volumes that are high for the sector. Aligning Manufacturing Readiness Levels (MRL) with part-specific applications will drive competitiveness and scalability.

Scaling up the manufacturing of e-mobility components efficiently remains a challenge, especially within the context of Europe's long and distributed supply chains. Leveraging digital twins and the industrial metaverse across the full production chain offers promising avenues for optimisation, yet their adoption is still limited.

Data connectivity across production sites, especially in cross-border and cross-company contexts, is hindered by cybersecurity concerns and interoperability issues. This limits the potential for integrated manufacturing ecosystems and real-time decision-making.

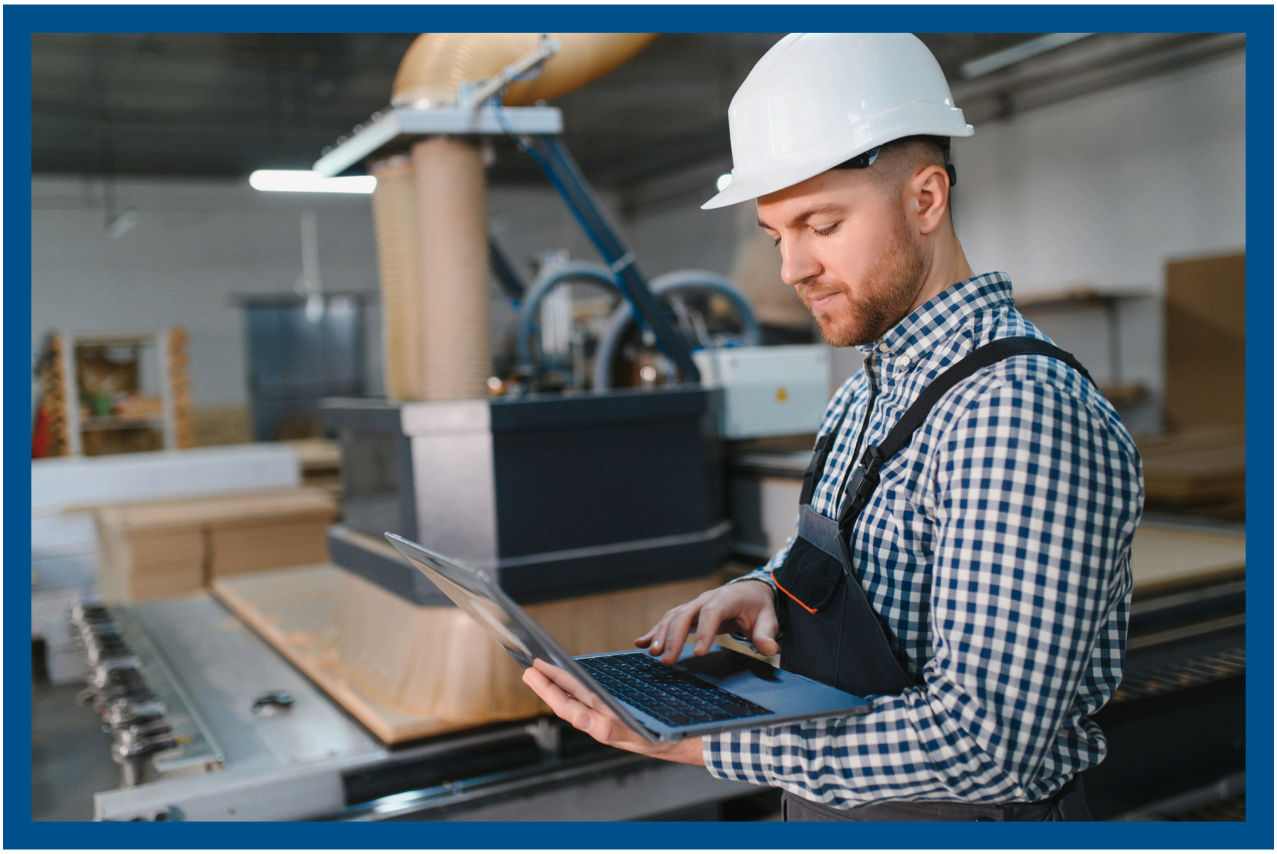
Collaborative design and validation of transport components across geographically distributed teams remain inefficient, highlighting the need for improved digital collaboration tools and methodologies.

3.4 Societal

Social acceptance of innovations in transport is another critical challenge. While high-level ambitions such as those outlined in the Fit for 55 package aim to accelerate the transition to sustainable mobility, their success hinges on public understanding and support. Bridging the gap between technological advancement and societal readiness is essential for achieving these goals.

Emerging mobility concepts, such as urban pods and shared ownership models, necessitate **new vehicle designs** that prioritize repairability and durability. Preparing for societal changes over the next decade requires forward-looking strategies that extend beyond the current framework programs.

Upskilling the workforce in areas such as automation, AI, circular design, and reverse logistics is essential to meet the evolving demands of transport manufacturing. The lengthy process from product design to production calls for advanced design approaches that exploit AI, digital tools, and robotics (incl. cobots) to accelerate innovation cycles and ensure competitiveness.



4 Research & Innovation Priorities and Recommendations

To address the multifaceted challenges outlined above, a comprehensive set of research and innovation priorities must be pursued.

Novel efficient production methods shall be developed to address changed market needs. To advance sustainability and resilience in transport manufacturing, it is essential to prioritise energy-efficient production methods, particularly by minimising the need for long-distance transport of components through localised manufacturing strategies.

Complementing this, the adoption of innovative manufacturing techniques such as AI-supported machining and optimized forming processes can significantly reduce energy consumption and/or waste while enhancing precision and productivity. At the systemic level, the development of circular business models for de-manufacturing and re-manufacturing is crucial to support sustainable industrial ecosystems, enabling the reuse of materials and components, mitigating critical raw materials, and reducing overall environmental impact.

- Novel, efficient production methods for higher requisite market volumes.
- Energy-efficient production methods are paramount, including strategies to reduce the transport of parts through localized manufacturing.
- New manufacturing strategies that reduce energy consumption and/or waste, such as AI-supported processes and optimal forming steps, should be explored.
- Circular business models for de- and re-manufacturing must be developed to support sustainable industrial ecosystems.

To enhance vehicle efficiency and reduce environmental impact, the development of lightweight, smart, and sustainable structures with inherent reusability is essential. This requires a shift toward engineering new components and platforms that not only minimize weight but also lower energy consumption throughout the vehicle lifecycle. Central to this effort is the adoption of advanced, high-strength and/or light materials such as alloys, steels, and composites, which enable both structural performance and multifunctionality, supporting the dual goals of sustainability and technological advancement in transport manufacturing.

- Lightweight, smart, and sustainable structures with elements of reusability should be developed to enhance vehicle efficiency and reduce environmental impact.
- New components and platforms should be engineered to reduce both weight and energy consumption.
- Advanced, high-strength and/or light materials, including alloys, steels, and composites, should be used to achieve component lightweighting and multifunctionality. It will be necessary to advance further in manufacturing technologies to process these novel materials.

To support a truly circular and sustainable manufacturing ecosystem, it is vital to embed recyclability into the design of materials and components from the outset, particularly when substituting (critical) raw materials with more sustainable alternatives.

The development and use of recyclable materials tailored for additive manufacturing play a key role in this transition, enabling more efficient material recovery and reuse. In parallel, advanced joining technologies are needed to accommodate difficult-to-weld alloys, composites, and hybrid structures, ensuring structural integrity without compromising recyclability.

The integration of digital passports to monitor material degradation and corrosion further enhances traceability, extending material lifetime, and facilitating responsible end-of-life management. Recyclable materials for additive manufacturing and advanced joining technologies for difficult-to-weld alloys, composites, and hybrid structures are also critical.

- Material and component design must incorporate recyclability considerations from the outset, especially when substituting raw materials.
- Tailored recycled materials for additive manufacturing, along with digital passports to track degradation and corrosion, will improve material lifetime and recyclability.
- Advanced joining technologies for difficult-to-weld alloys, composites, and hybrid structures ensuring further recyclability.

To fully harness the potential of digital transformation in transport manufacturing, digital twins must be systematically leveraged for the design and development of components, including advanced material modeling and transformation processes, and throughout their full lifecycle. Achieving interoperability and scalability requires the standardisation of digital twins and model building blocks, enabling the development of full system-level products. In parallel, mixed reality (MR) and virtual reality (VR) collaboration tools can significantly enhance distributed co-engineering of transport modules, provided that usability frameworks are in place to address ergonomic, cultural, and cognitive barriers, especially in high-stakes environments. Virtual homologation processes offer a streamlined path to certification and compliance, while robust reverse logistics systems are essential to manage the lifecycle of batteries and other critical components.

Embedding design-for-de-manufacturing and re-manufacturing principles into product development will facilitate the reuse and recycling of complex materials such as composites and hybrid joints. To ensure safety and performance, standardised procedures for evaluating reused components must be established, covering protocols, data evaluation, and decision-making frameworks.

- *Digital twins should be leveraged for the design and development of components, including material modeling and transformation processes.*
- *Standardization of digital twin and model building blocks is necessary for the development of full system-level products.*
- *Mixed reality (MR) and virtual reality (VR) collaboration tools will facilitate distributed co-engineering of transport modules, while usability frameworks for XR adoption must address ergonomic, cultural, and cognitive barriers in high-stakes environments.*
- *Virtual homologation processes can streamline certification and compliance*
- *Reverse logistics systems must be developed and scaled to manage the lifecycle of batteries and other critical components.*
- *Design for de-manufacturing and re-manufacturing must become standard practice, enabling the reuse and recycling of materials such as composites and hybrid joints.*
- *Standardized procedures for evaluating reused components will ensure safety and reliability.*

The integration of advanced automation and intelligent systems is pivotal for the future of transport manufacturing. XR interfaces, when designed to interact seamlessly with digital twins, can enable intuitive diagnostics and predictive maintenance, enhancing operational efficiency and reducing downtime.

In parallel, energy-efficient AI-based computer vision technologies offer real-time defect detection, significantly improving quality control across production lines without using large experimental datasets for training. To support modular and adaptive manufacturing, flexible manufacturing cells capable of performing diverse tasks are essential, allowing for rapid reconfiguration and responsiveness to changing demands.

Robotics and virtual aids play a critical role in the construction and maintenance of complex transport infrastructure, such as internal wiring in aircraft and rail systems, where precision and repeatability are paramount. Harmonising homologation procedures across Europe will be key to facilitating the widespread deployment of these technologies.

Furthermore, advancing automation and robotics (incl. cobots) for efficient disassembly and reconditioning of complex components will be crucial to enabling scalable circular manufacturing practices.

- *XR interfaces should be designed to interact with digital twins, enabling intuitive diagnostics and predictive maintenance.*
- *Energy-efficient AI-based computer vision can detect defects in real time, improving quality control on production lines without using large experimental datasets.*
- *Flexible manufacturing cells capable of performing diverse tasks will support modular production strategies and flexible manufacturing systems, together allowing truly high-mix, low-volume manufacturing.*
- *Robotics and virtual aids are essential for the construction and maintenance of transport infrastructure, including internal wiring in aircraft and rail systems. Harmonizing homologation procedures across Europe will facilitate the deployment of these technologies.*
- *Automation and robotics (incl. cobots) should be advanced to enable efficient disassembly and reconditioning of complex components.*

As societal trends such as remote work, flexible schedules, and increased mobility reshape the industrial landscape, factory concepts must evolve accordingly.

Embracing deeper digitalisation will be key to enhancing agility, responsiveness, and resilience in manufacturing operations. In parallel, immersive extended reality (XR) platforms offer powerful tools for workforce development, enabling precise and safety-compliant training in the assembly and maintenance of complex transport systems.

These technologies not only support upskilling but also ensure that workers are equipped to adapt to the demands of next-generation manufacturing environments. The use of LLMs can also streamline the training operations for the workforce.

- *Factory concepts must evolve in line with societal trends such as remote work and increased mobility. Further integration of digitalization will enhance agility and responsiveness in manufacturing operations.*
- *Immersive XR platforms can train workers in the assembly and maintenance of transport systems, ensuring precision and safety compliance.*
- *Use of LLMs for training purposes*

5 Conclusion

The transport manufacturing sector stands at a pivotal juncture, facing complex challenges that demand coordinated and forward-looking research and innovation efforts. By addressing environmental concerns, enhancing competitiveness, and embracing digital and circular manufacturing paradigms, Europe can secure its leadership in sustainable transport solutions. The recommendations outlined in this brief provide a roadmap for stakeholders, including policymakers, industry leaders, and research institutions, to collaborate effectively.

Through strategic investments in enabling technologies, skills development, and infrastructure, the European transport manufacturing ecosystem can evolve to meet future demands.

EFFRA remains committed to supporting this transformation by fostering dialogue, aligning priorities, and driving innovation across thematic working groups. Together, we can build a resilient, efficient, and sustainable transport manufacturing landscape for Europe.

R&I Brief

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