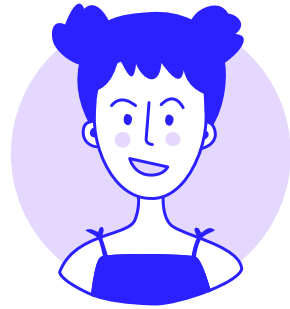




CE TRACK

Circular Economy Training, Roadmap and Applied Circular Knowledge





Hi! I am Jody. Your guide for today. Let's start with an introduction.

1 Introduction to the Roadmap

1.1 Background and Relevance

This Circular Economy Knowledge Creation Roadmap was developed in response to a key research question: **How can knowledge of the circular economy be developed and embedded within the field of aviation maintenance?** Based on empirical findings, four recurring themes emerged which informed the design of this roadmap.

1. **Trade-offs** in decision-making
2. **The (mis)understanding** of sustainability
3. **Wait and see attitude** slows down sustainability innovation
4. **Cooperation** remains unstimulated

These challenges highlight the structural and cultural obstacles to achieving circularity within the aviation maintenance sector. For instance, although the concept of sustainability is widely accepted, its meaning can vary significantly from one department to another, which can lead to **misunderstandings** or a **lack of engagement**. While it is understandable that maintenance professionals prioritise **cost**, **safety** and **performance**, this can obscure the **long-term value creation** that circular thinking can deliver.

The roadmap addresses this complexity. Rather than offering a prescriptive path, it provides a **flexible framework** to help professionals reflect on their current practices, experiment with new approaches and gradually integrate circular principles into their daily operations. It recognises that transformation does not happen all at once, but requires **collective learning**, **cultural alignment** and the **development of targeted knowledge** over time.

The four themes introduced above are reflected across the roadmap's three phases. For example, phase 1 focuses on **building a shared understanding** and **clarifying terminology**, which addresses theme two. Phase 2 highlights **regulatory developments** and the **need for strategic direction**, making theme three more actionable. Phase 3 emphasises **systems thinking** and **collaboration**, directly addressing theme four. Theme one, decision-making, is woven throughout all phases.

By explicitly linking these issues to specific action phases, the roadmap translates abstract ambitions into practical steps.

1.2 Roadmap Design

The roadmap design is grounded in design roadmapping theory by Simonse (2024). The roadmap outlines a phased, long-term learning process tailored to professionals in maintenance, engineering, and related domains. It organises the six circular economy knowledge areas into a coherent structure that supports both individual learning and organisational change. Rather than positioning circularity as an abstract goal or technical challenge, the roadmap shows how it can become a valuable and realistic part of maintenance work. It builds trust by clarifying what circularity means in this specific context, and by offering tangible examples of what can be done in each phase.

This journey unfolds across three key phases:

1. **Sense-Making:** making sense of the circular economy within the maintenance context.
2. **Explore Together:** collaboratively identifying and testing the circular economy's potential in practice.
3. **Integration:** embedding lessons learned into existing ways of working to enable sustainable transformation.

Each horizon builds upon the previous one and supports gradual change. The roadmap does not prescribe a fixed timeline. Instead, it is designed to be adaptable to different teams and organisational contexts. Importantly, it includes user typologies that represent four common professional attitudes within NLR. These typologies help to ensure that the roadmap resonates with diverse audiences and encourages inclusive dialogue.

1.3 Predictive Technology as a Case Study

To make the roadmap more concrete, a predictive maintenance tool is used as a recurring case study. This technology, developed within the aerospace context, leverages advanced diagnostics and predictive capabilities to detect component failures and optimise maintenance interventions.

In this roadmap, predictive technology illustrates how digital tools can support circular economy adoption. By integrating circular KPIs into models and dashboards, such tools enable engineers and managers to better understand how maintenance decisions impact long-term value, reuse potential, and material flows.

This technology is not presented as the only or ideal solution. Instead, it serves as a working example of how existing digital capabilities can be aligned with circular goals. The case study helps bridge the gap between abstract principles and operational relevance. It demonstrates how circularity can be made visible, measurable, and actionable—starting from tools already in use.

By following the predictive technology through the different phases, the roadmap shows how any product, process, or capability can evolve over time to better support circular outcomes. This approach makes the roadmap applicable beyond this one case and highlights how knowledge creation can be embedded in real-world innovation.

2 Meet the Four Faces of Circularity

Understanding the Four Typologies

Sustainability. Circularity. Regulation. Change. These are big topics. But how we experience and act on them often depends on the work we do, the responsibilities we hold, and the values we prioritise.

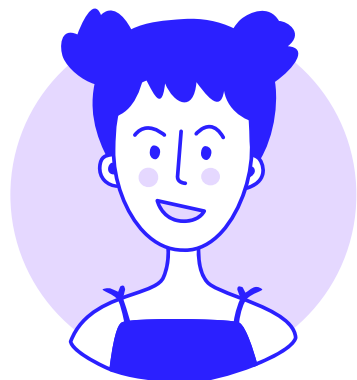
At NLR, people approach circularity in different ways. Based on interviews and real conversations, four common voices emerged. These typologies are not stereotypes or fixed roles. Instead, they represent patterns in how people think, work, and talk about change. They help us understand where others are coming from and where we might go together.

In this roadmap, each step is built around a value that plays a key role in moving circularity forward. To make this value more tangible, one typology

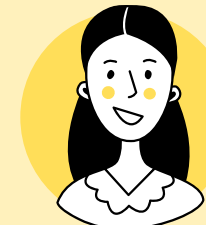
is highlighted per step. This does not mean that only one group is responsible for progress at that point. Everyone remains involved throughout. Circularity is a shared journey, not a solo task.

The reason for highlighting one voice per step is simple: it helps bring focus to specific concerns, motivations, and types of contribution that are especially relevant at that point in the roadmap. But all typologies are in motion. They each bring something different and essential to the transition.

Let the four typologies introduce themselves. You might recognise one, or maybe parts of several. Use them as a tool for reflection and conversation, not as a label. Together, they reflect the diversity of thinking that circular change requires.



The Cautious Guardian



Anna

I find sustainability important, but only after safety and compliance have been fully secured.

“If something isn’t 100% safe, it will never be allowed in aviation, no matter how sustainable it is.”

The Motivated Explorer



Jeroen

I am intrinsically motivated to contribute to sustainability, but I miss the right structures, shared language or support.

“We’re not overwhelmed with questions... we do what we can!”

The Business Realist



Milan

I embrace circularity as long as it saves money, time or offers a competitive edge.

“It uses 20% less energy. That’s great for the environment, but mostly because it’s cheaper.”

The Technically-Driven Doer



Farah

Circularity is about smart engineering and effective maintenance, not ideology.

“Maintenance is what enables circularity.” & “A good maintenance concept needs to be built into the design phase.”

3 Strategic Roadmap



Your are about to read the **Strategic Roadmap**. Let me give you some instructions!

2 Then you can move on to the 3 phases.

3 You read the phases from left to right.

1 The roadmap starts with the future vision, the goal that we will work towards.

Netherlands Aerospace Centre

Master Thesis of Julia van Mens
July 2025

Strategic Roadmap

Our Future Vision

Working Together Towards Circular Maintenance

By 2035, NLR's maintenance engineers will share a **practical language of circularity** and drive **strong partnerships** and **system-wide innovation**.

GOAL	PROBLEM TO SOLVE	KNOWLEDGE	USER GROUP VALUES
<p>Sense-Making 2025/2026</p> <p style="font-size: 0.7em; margin-top: 5px;"><i>Exploring the meaning and added value of circularity while also creating ownership.</i></p>	<p style="font-size: 0.7em; margin-top: 5px;">Low clarity and confidence and Circularity feels abstract and distant. "I kind of get what circularity is, but I wouldn't know how to explain it to a customer."</p>	<p style="background-color: #4a7c9c; color: white; padding: 5px; border-radius: 5px;">Foundational Cultural Strategic</p>	<p style="font-size: 0.7em; margin-top: 5px;">Motivated Explorer</p> <div style="display: flex; gap: 5px;"> <div style="border: 1px solid #ccc; border-radius: 10px; padding: 2px 5px; font-size: 0.7em;">Ownership</div> <div style="border: 1px solid #ccc; border-radius: 10px; padding: 2px 5px; font-size: 0.7em;">Simple & Shared Language</div> <div style="border: 1px solid #ccc; border-radius: 10px; padding: 2px 5px; font-size: 0.7em;">Awareness of Added Value</div> </div>
<p>Explore Together 2027/2029</p> <p style="font-size: 0.7em; margin-top: 5px;"><i>Taking the first steps with a trusted, long-standing partner.</i></p>	<p style="font-size: 0.7em; margin-top: 5px;">Teams want to try circular ideas, but miss support, examples and room to fail. "We want to try more sustainable options, but we don't know where to start or who to involve."</p>	<p style="background-color: #4a7c9c; color: white; padding: 5px; border-radius: 5px;">Practical Institutional</p>	<p style="font-size: 0.7em; margin-top: 5px;">Cautious Guardian</p> <div style="display: flex; gap: 5px;"> <div style="border: 1px solid #ccc; border-radius: 10px; padding: 2px 5px; font-size: 0.7em;">Evidence-Based Action</div> <div style="border: 1px solid #ccc; border-radius: 10px; padding: 2px 5px; font-size: 0.7em;">Regulatory Awareness</div> <div style="border: 1px solid #ccc; border-radius: 10px; padding: 2px 5px; font-size: 0.7em;">Prototyping Culture</div> </div>
<p>Integration 2030/2035</p> <p style="font-size: 0.7em; margin-top: 5px;"><i>Making circularity the new normal and focusing on systemic impact.</i></p>	<p style="font-size: 0.7em; margin-top: 5px;">Even with growing momentum, circularity still lacks clear roles, metrics and ownership. "We do small projects, but there's no system or ownership to make it part of our strategy."</p>	<p style="background-color: #4a7c9c; color: white; padding: 5px; border-radius: 5px;">Systematic Strategic</p>	<p style="font-size: 0.7em; margin-top: 5px;">Business Realist</p> <div style="display: flex; gap: 5px;"> <div style="border: 1px solid #ccc; border-radius: 10px; padding: 2px 5px; font-size: 0.7em;">Measurability of Outcomes</div> <div style="border: 1px solid #ccc; border-radius: 10px; padding: 2px 5px; font-size: 0.7em;">Value Chain Collaboration</div> <div style="border: 1px solid #ccc; border-radius: 10px; padding: 2px 5px; font-size: 0.7em;">System-Wide Credibility</div> </div>

3 Strategic Roadmap



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Working Together Towards Circular Maintenance

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GOAL

PROBLEM TO SOLVE

KNOWLEDGE

USER GROUP VALUES

Sense-Making
2025/2026

Exploring the meaning and added value of circularity while also creating ownership.

Circularity feels abstract and distant. "I kind of get what circularity is, but I wouldn't know how to explain it to a customer."

Foundational
Cultural
Strategic

Motivated Explorer



- Ownership
- Simple & Shared Language
- Awareness of Added Value



Explore Together
2027/2029

Taking the first steps with a trusted, long-standing partner.

Teams want to try circular ideas, but miss support, examples and room to fail. "We want to try more sustainable options, but we don't know where to start or who to involve."

Practical
Institutional

Cautious Guardian



- Evidence-Based Action
- Regulatory Awareness
- Prototyping Culture



Integration
2030/2035

Making circularity the new normal and focusing on systemic impact.

Even with growing momentum, circularity still lacks clear roles, metrics and ownership. "We do small projects, but there's no system or ownership to make it part of our strategy."

Systematic
Strategic

Business Realist



- Measurability of Outcomes
- Value Chain Collaboration
- System-Wide Credibility





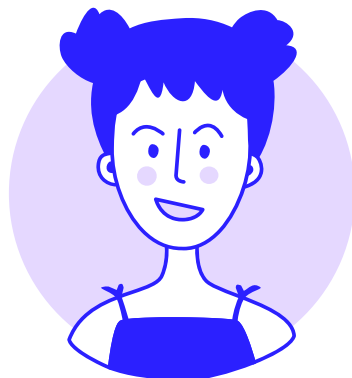
To give meaning to the strategic roadmap, a **tactical roadmap** was developed. The tactical roadmap contains much more detail.

The most significant change is that the future horizon is now positioned at the end of the roadmap, serving as a clear objective towards which we are working.

The phases are now structured horizontally, with the specific details for each phase structured vertically below.

In order to understand how the content of the tactical roadmap is created, it is important to explain the five building blocks of the tactical roadmap.


The next page contains general information about the phases to provide an initial overview.



Future Vision

By 2035, NLR's maintenance professionals will speak a shared and practical language of circularity — enabling strong partnerships for circular innovation and a systemic focus. This shared mindset will support the integration of circular economy strategies into maintenance tools and practices.

Circularity is used not to make everything circular, but to design a system that can sustain itself — resilient against material scarcity, regulatory pressure, and rising energy demands. From early ideas to certified solutions, it's a strategic mindset embedded in engineering reality.





The first phase lays the foundation for cultural and behavioural change by building a **basic, shared understanding** of circular economy principles within the aviation maintenance context. Maintenance professionals, particularly those fitting the **Motivated Explorer typology**, are engaged through accessible tools such as the **Circular Economy Storybook** and targeted workshops. The focus is on **fostering foundational, practical, and behavioural/cultural knowledge**: using consistent terminology, recognising circularity as relevant to maintenance work, and connecting existing practices with 10R strategies (with an emphasis on R1 Rethink, R3 Reuse, R6 Remanufacture, and R8 Recycle). Early discussions aim to build **ownership and curiosity**, preparing the organisation for more advanced learning and **collaboration** in the next phase.

In parallel, maintenance professionals begin exploring how digital tools such as predictive technologies could support circular outcomes. Through workshops and facilitated sessions, teams discuss which circular economy KPIs might be meaningful for predictive maintenance and diagnostics. A structured mapping of the current data landscape and functional potential of the technology is conducted, identifying gaps and opportunities to enhance circularity through digital support. The outcome is an initial awareness of predictive maintenance's role in material retention and lifecycle extension, alongside a first prioritised list of relevant circular economy KPIs for further development in Horizon 2.

In the second phase, learning shifts from conceptual to **experiential**. Strategic and institutional knowledge development takes centre stage through applied **learning pilots** in collaboration with external partners, such as the **Ministry of Defence**. Maintenance professionals — now including more **Cautious Guardian** profiles — gain hands-on experience applying **circular KPIs, collaborating across the value chain, and managing trade-offs** between circularity, cost, and safety. Emerging regulations (**CRMA, CSRD, ESRP, DPP**) are translated into practical implications through the pilots. Insights from these experiments are carefully documented, creating **organisational learning** that prepares for broader internal adoption and scaling in Horizon 3.

Predictive technology now takes an active role in the applied learning pilots. Selected circular economy KPIs from Phase 1 are implemented in a prototype KPI dashboard within the tool. Maintenance teams and pilot partners use the system to monitor lifecycle extension rates, remanufacturing potential, and circular flows of critical materials. For example, in one pilot, the technology is used to track material loops and identify opportunities for remanufacturing and reuse of key components. Maintenance professionals gain experience interpreting these outputs and applying them in operational decision-making. This phase also marks the beginning of data integration between predictive technology and broader MRO and sustainability reporting systems, enabling comprehensive tracking of circular performance.

The third phase focuses on **embedding** circularity into everyday organisational processes and systems. **Systems knowledge** becomes the priority, supported by continued strategic and institutional learning. Circular economy principles are **integrated** across maintenance workflows, decision-making tools, and data management practices. **Cross-departmental collaboration** (between engineering, sustainability, and data science teams) becomes more structured, and external partnerships expand. **The Business Realist** typology becomes increasingly central as circularity is positioned as a means to deliver **measurable operational, regulatory, and business** value. The organisation aligns its practices with evolving **industry standards** and regulatory frameworks, transforming circularity from a side initiative into a core part of MRO strategy.

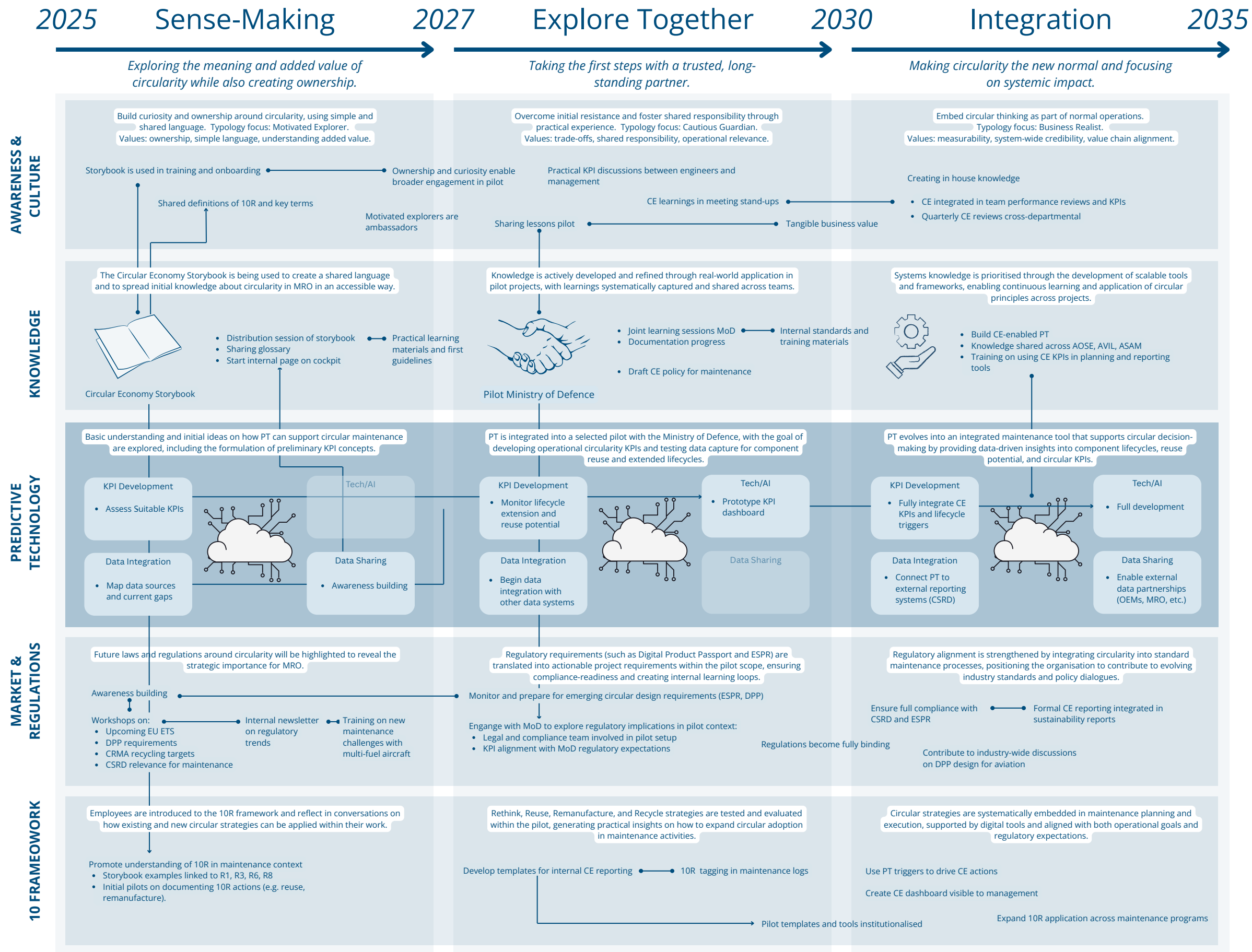
In Phase 3, predictive technology evolves into a fully circularity-enabled decision support tool. Circular KPIs are now embedded in its core functionality, and its predictive models actively inform decisions related to lifecycle extension and component remanufacturing. Maintenance workflows rely on insights from the tool to guide actions that align with circularity principles. Data streams from the technology are fully integrated into MRO planning systems and external reporting frameworks (such as CSRD and DPP), supporting regulatory compliance and demonstrating leadership in circular maintenance. Furthermore, data is shared with OEMs and MRO partners through industry collaboration initiatives, contributing to the development of shared circular standards and best practices across the aviation sector.

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