CIRCULARITY IN AVIATION MRO OPERATIONS

Designing for Circular Value Retention in Repair Capability Decisions

Master Thesis

Joep van Gils

TU Delft

KLM engineering & maintenance

Author
Joep van Gils

Master of Science in Strategic Product Design
Faculty of Industrial Design Engineering
Technical University of Delft
To be publicly defended on 24/02/2026

Thesis Committee
Chair: **Dr.ir. R.G.H. (Bart) Bluemink**
Mentor: **Ir. P.A. (Peter) Kraaijeveld**

Company
KLM Engineering & Maintenance
Mentor: **Joyce Lustenhouwer**

ACKNOWLEDGEMENTS

During my studies, my greatest driver was always my curiosity. I have always enjoyed diving into new industries, topics and worlds to understand how they work and where opportunities might sit. This graduation project offered a lot of that. I really enjoyed working in this complex and constrained environment and gradually starting to understand it, while still being far from a complete view. Working close to the operation and exploring the hangar only sparked this curiosity and motivation further.

This deep dive was made easier by two things. First, Joyce was a huge help in our constant conversations, help in scoping and in answering every question I had, for which I am very grateful. Second, the passion and pride people showed in their work and in being a KLM E&M employee. Everyone I spoke to was eager to help, and I am thankful for that openness. It left a strong impression on me. It also shaped what I will look for after graduation: a place where people are proud of what they do and what the organisation stands for, even if your own role is not always right next to the operation.

I also want to thank Linda for her confidence in me after our initial meetings and the short project before the summer and offering me the chance to graduate at the Technology Hub.

Finally, I want to thank Bart for his guidance throughout the thesis: helping me on the way at the beginning and steering the direction, pushing me when needed, giving sharp feedback and helping me move from research insights to a coherent final deliverable. The same goes for Peter, who also pushed me to keep visualising and storytelling so that design elements remained central in both the work and the written thesis.

- Joep

ABSTRACT

This thesis investigates how KLM Engineering & Maintenance can integrate circularity into aviation MRO decision-making to retain value in parts by redesigning how routed-part outcomes are made visible, comparable, and steerable in daily work. The research is grounded in part routing in the Salvation & Warranty context, where parts move through a sequence of gates under contractual, technical, and operational constraints, and where circular value is often lost.

A qualitative case-study design was applied, structured through five sub-questions that move from reconstructing the as-is routing system and decision funnel to defining and operationalising circularity at part level. Data collection combined semi-structured interviews across roles, follow-up clarification meetings to validate the evolving routing map and gate logic and a co-creation workshop to test indicator feasibility and shared understanding under operational constraints.

The thesis contributes a set of design requirements for circular routing decision-making, a linked indicator system that operationalises circular value retention through routed-part outcomes (R-levels) and adds steering and prioritisation layers (R-ratio trend steering, Functional Lifetime Loss based on benchmark service potential, and an indicative CO_2 effect based on internal carbon assessment factors) and a staged implementation roadmap in three horizons that separates foundation building (shared language), stable logging and steering, and long-term embedding through governance and an external repair ecosystem. These deliverables were brought together in the form of an interactive website to make it workable and distributable for KLM E&M.

TABLE OF CONTENTS

ABBREVIATIONS

AFI KLM E&M	Air France Industries KLM Engineering & Maintenance
AOG	Aircraft On Ground
AVL	Approved Vendor List
BER	Beyond Economic Repair
BM	Business Model
CBM	Circular Business Model
CE	Circular Economy
CIRCADIS	Advancing Cabin Sustainability and Operational Efficiency Through Cross-Industry Design with Lightweight Materials
CMM	Component Maintenance Manual
CPC	Checkpoint Charlie
CRR	Circular Retention Rate
CS	Component Services
CSCM	Circular Supply Chain Management
DOA	Design Organisation Approval
E&M	Engineering & Maintenance
EOL	End-of-Life
EOU	End-of-Use
EPA	European Part Approval
EU	European Union
FLL	Functional Lifetime Loss
IATA	International Air Transport Association
ISO	International Organization for Standardization
KLM	KLM Royal Dutch Airlines (Koninklijke Luchtvaart Maatschappij)
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
MAR	Missing At Random
MCAR	Missing Completely At Random
MEF	Material, Equipment & Facilities (department within KLM E&M)
MNAR	Missing Not At Random
MRO	Maintenance, Repair and Overhaul
OEM	Original Equipment Manufacturer
ORL	Operational Readiness Level
PMA	Parts Manufacturer Approval
POA	Production Organisation Approval
R-level	R-strategy level (value retention option classification, e.g., R3–R9)
RR	Repair Ratio (share of items routed to repair versus other options)
SAF	Sustainable Aviation Fuel
SAP	SAP ERP system (Systems Applications & Products in Data Processing)
SBM	Sustainable Business Model
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference model
S&W	Salvation & Warranty
TAT	Turnaround Time (time to complete a maintenance/repair event)
TISE	Time-in-Service Equivalent (lifetime/usage-equivalent metric for parts)
TNO	Netherlands Organisation for Applied Scientific Research (TNO)
TRL	Technology Readiness Level

1.1 RESEARCH ASSIGNMENT & THESIS FOCUS

Project embedding (CIRCADIS)

This graduation project is preparatory for CIRCADIS: Advancing Cabin Sustainability and Operational Efficiency Through Cross-Industry Design with Lightweight Materials. CIRCADIS unites TU Delft, Airbus, KLM Engineering & Maintenance, material experts and production partners to make sure innovations are technically feasible and operationally applicable by integrating design, material technology and maintenance processes into one approach.

Assignment positioning

This thesis contributes as laying the groundwork for the CIRCADIS work package on restorative resource use by developing methods that combine circular design with prospective life cycle assessment (LCA) for aerospace supply chains and products.

Problem statement (operational focus)

Circularity is not yet translated into consistent, day-to-day decision-making in KLM E&M MRO operations. As a result, value-retention choices (repair/replace/scrap) are primarily steered by operational and financial drivers, while circular value loss remains insufficiently visible, comparable, and governable.

This is also relevant for sustainability choices because if emissions are not visible at ground level, it cannot be steered. This way CO_2 ambitions stated in KLM's Climate Action Plan (2022) remain separate from day-to-day repair and replacement decisions.

Main research question

How can KLM E&M integrate circularity into aviation MRO decision-making to retain value in parts?

1.2 END DELIVERABLE: THE CIRCULAR BLUEPRINT

The thesis delivers a Circularity Blueprint for KLM Engineering & Maintenance (E&M). The Blueprint is developed as a interactive website in E&M language and context, with clear instructions for use. This format is chosen to make the output operationally workable, easy to distribute across the organization, and less likely to remain a static document that is read once and then stored away and forgotten.

The Blueprint combines three integrated parts:

1. **Circular value indicators:** a standardized set of signals used in routing and decision moments to make value retention and value loss visible and comparable across cases.
2. **Strategic roadmap:** a direction-setting horizon view (visibility→steering→ governance/embedding).
3. **Tactical roadmap:** execution-steering actions, responsibilities, success criteria, and adoption logic per horizon.

1.3 GRADUATION CONTEXT: THE TECHNOLOGY HUB

This thesis was conducted within the Technology Hub of E&M. The Tech Hub supports innovation in MRO by bringing focus to initiatives that would otherwise stay scattered across departments. It works with internal teams and external partners to explore ideas and translate what works into solutions that can be used in daily operations.

The Tech Hub works through four roles: scouting, exploring, creating and facilitating. It identifies needs and opportunities (scouting), tests ideas with users and experts (exploring), develops and trials workable prototypes (creating) and supports adoption in the line organisation (facilitating).

To manage handover realistically, the Tech Hub uses two lenses, shown in appendix A: Technology Readiness Levels (TRL) and Operational Readiness Levels (ORL). TRL tracks whether something works technically. ORL tracks whether E&M can actually run it: clear users, ownership, procedures, stable performance and integration in existing routines. In MRO this distinction matters because operational risk, certification constraints and turnaround pressure are high; a solution only becomes valuable when it fits the operation.

The Tech Hub focuses mainly on mid-term (2–5 years) and long-term (5–10 years) topics, while staying connected to near-term needs by working closely with shop floors and engineering teams. It also collaborates with universities, research bodies, OEMs and suppliers to access knowledge and capability that is not always available in-house. Current themes include sustainability, data and automation, workforce, value-chain links and industry stability.

This setting fits the aim of this thesis: developing a clear foundation and implementation path for circularity that can be understood, discussed and applied by E&M teams in their existing way of working.

View on hangar 11 from the Technology Hub

1.4 RESEARCH STRUCTURE

The project is structured using the Double Diamond model for design processes, which distinguishes four phases: Discover, Define, Develop and Deliver (Design Council UK, 2015). Each phase alternates between diverging: to broaden the understanding of the situation and converging: to make clear choices and commitments. In this thesis the model serves as the main process framework. The activities, chapters and intermediate results are mapped onto the diamonds so that the progression from exploration to concrete design outcomes remains explicit and traceable throughout the project. The full diamond can be found in appendix B.

Because the initial scope, “circularity within KLM Engineering & Maintenance (E&M)” was too broad and vague for a graduation thesis, the standard Double Diamond is extended with a smaller, preliminary diamond. This additional diamond, labelled Explore and Scope, precedes the regular Discover phase. The Explore phase, field learning was done by conducting explorative interviews across departments to understand the complex aviation MRO context better. The goal was to understand where circularity issues appear in practice and which processes link most strongly to part value. In the Scope phase, these insights were narrowed down by comparing candidate topics on relevance for E&M, feasibility within the available time and access and their potential to lead to academic insights. This scoping step resulted in the selection of a specific department/process and the routing and decision process around dismounted parts as the scope for the rest of the thesis.

After this first initial diamond, the project enters the first full Double Diamond. In the Discover phase, focused context research is carried out on the selected routing, together with an initial literature review on circularity. Semi-structured interviews, internal documents and process mapping are used to reconstruct the “as-is” part routing, including actors, information flows, drivers and constraints. In parallel, the literature review develops a conceptual basis for circular strategies and value retention that can be applied to this context. In the Define phase, these empirical and theoretical insights are brought together. A more focused literature review on circularity in MRO and aviation is used to interpret the mapped routing, and the combined results are synthesized into a clear problem framing. At the end of this first diamond, the scope and problem are defined and concrete gaps, opportunities and shortcomings regarding circularity in the selected supply chain are identified. These outputs form the starting point for the second diamond, in which Develop and Deliver activities will use the defined problem and requirements to guide ideation, concept development and validation of improved decision principles for circular part value at E&M.

A more detailed planning can be found in appendix D.

1.5 METHODOLOGY

Research design

This graduation project used a qualitative case study within E&M, centered on cabin-related part routing decisions in the Salvation & Warranty context. The study followed a design logic in which qualitative field evidence is translated into design requirements, a circularity indicator set and a stepwise roadmap for implementation. The research was structured using five research sub-questions (SQ1–SQ5), moving from understanding the current routing system and decision funnel (SQ1–SQ4) toward defining and operationalising circularity through feasible indicators and integration logic (SQ5).

Data collection strategy and sampling

Data collection combined (1) expert and semi-structured interviews, (2) follow-up clarification meetings, and (3) a co-creation workshop to test and refine indicator logic in a realistic operational framing. Semi-structured interviewing was used to balance comparability across participants with enough flexibility to probe decision moments, exceptions, and constraints. Sampling was with purpose and iterative: initial participants were selected as key informants for S&W routing and repair development and additional participants were included via snowball sampling when specific gaps emerged. Snowball sampling is widely recognized as an effective technique for accessing hard to-reach groups and enhancing participation through social connections (Ting et al, 2025). Follow-up meetings were used for illumination and elaboration: validating the evolving routing map, correcting terminology, and filling missing gate rules or information dependencies.

Participants were anonymised and described only by role and domain (e.g., MEF supply chain analyst). The participant overview table (Appendix K) documents domain coverage, interview type, sampling strategy and how each meeting contributed to thesis outputs. Appendix L contains a protocol matrix as overview

Interview and meeting procedures

Interviews focused on gathering concrete decision evidence rather than general opinions: gate rules, thresholds, triggers for repair development, ownership boundaries, information availability, and operational constraints. Follow-up meetings were used to review the evolving part routing map and align it with operational reality, including categorisation practices and how scarcity and lead-time signals are monitored.

Meetings were conducted mostly in Dutch, reporting was done by transcribing into English memo sheets. Appendix M contains per-meeting memo sheets that capture the purpose of the visit, main insights, and how each meeting informed the next design step . This format provides traceability without exposing identities or sensitive operational details.

Justification for heavy reliance on interviews

This study relies mainly on semi-structured interviews because **E&M is a closed, safety- and contract-bounded operation in a niche sector in which decision rules are distributed across roles and often remain tacit rather than documented as one coherent process.** Gate outcomes depend on timing, ownership, and interpretation of information (warranty authority, approved repair options, cost/lead-time risk, scarcity signals) and those dependencies are not fully visible from systems outputs alone. Interviews therefore functioned as the primary method to reconstruct the decision funnel as it is actually practiced: identifying gate rules, exceptions, handovers, and constraints under time pressure. Internal documents and process mapping were used to triangulate terminology and formal responsibilities, while follow-up meetings were used to validate and correct the evolving routing map and fill missing dependencies. A co-creation workshop then stress-tested whether the emerging indicator logic fits the real decision setting rather than an abstract circularity model.

Co-creation workshop: circularity indicator logic

A co-creation workshop was conducted with three role perspectives (MEF supply chain, sustainability, Repair Lab engineering) to explore how circular value could be recognised at part level and how indicator ideas would perform under real operational constraints. Co-creation was used to surface friction between perspectives and to test whether indicator logic is understandable, workable, and adoption-ready (Sanders & Stappers, 2008).

Data analysis approach: deductive coding and synthesis

Analysis used a deductive coding structure aligned to the research sub-questions and key decision moments in MRO routing. The coding structure was developed iteratively alongside the research process to keep categories while allowing adjustment as new operational insights emerged (Miles et al, 2014). Interview and workshop material was segmented into meaning units, assigned operational codes and combined into higher-level findings that were then used to create design outputs (requirements, indicator logic, and roadmaps). The resulting coding and the mapping from coded evidence to findings are provided in Appendix O.

Trustworthiness and quality measures

Credibility was strengthened through triangulation across roles and domains: routing descriptions and gate rules were checked through multiple perspectives and through iterative validation of the routing map in follow-up meetings. The co-creation workshop acted as an additional check on interpretation by exposing indicator ideas to operational critique and correcting assumptions during discussion. Dependability and confirmability were supported by maintaining an audit trail: participant overview, protocol matrix, coding and coded findings mapping.

Ethical and confidentiality handling

Participants are anonymised in reporting and appendices using P-codes and generic role titles. Meeting notes and derived memo sheets avoid disclosing names and sensitive operational details beyond what is required for the argumentation and findings for this thesis.

II

Field Learning

Understanding KLM E&M and the aviation MRO context

GOAL

Build a clear picture of KLM E&M as an operation and of the wider aviation MRO world by understanding the drivers, pressures, and constraints

FOCUS

1. What is aviation MRO?
2. What role has KLM E&M in this ecosystem?
3. What role can strategic design play in a regulated, availability-driven operation?

METHODOLOGY

1. Explorative interviews with stakeholders across E&M
2. High-level mapping of organization structure
3. Literature review for understanding context

2.1 CONTEXT: AVIATION, KLM & SUSTAINABILITY

The global aviation industry is characterized by long investment cycles, complex supply chains and strong exposure to geopolitical and economic change. Despite recent shocks such as supply chain disruptions, rising costs and trade pressures, air transport remains essential for global connectivity and economic activity. In 2024, worldwide passenger traffic exceeded pre-pandemic levels and demand is expected to rise further in the coming years, especially in Asia and Europe (IATA, 2025).

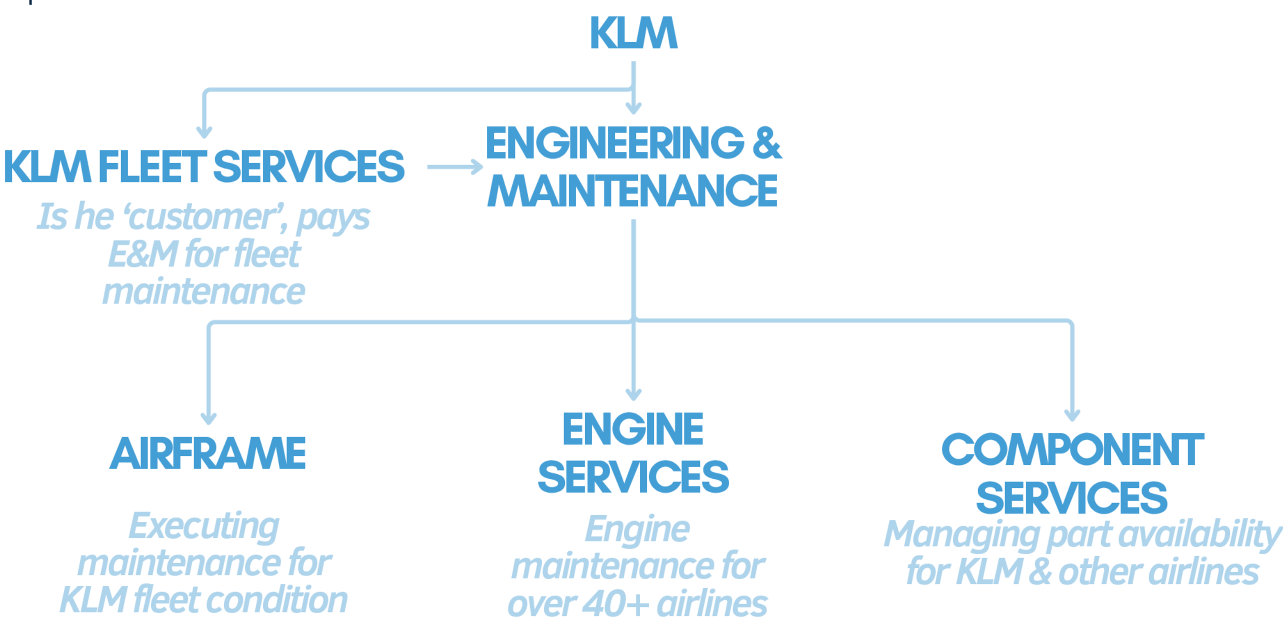
This growth coincides with increasing environmental demands, regulatory pressure and technological transition. In this context, KLM Royal Dutch Airlines must balance financial stability with the ambition to become a frontrunner in sustainable aviation (KLM, 2024). Its strategy combines investments in new aircraft, sustainable fuels and digital tools with measures aimed at improving cost efficiency and restoring resilience, as seen in figure 1. According to KLM's Climate Action Plan (2023), this approach is structured around four main levers: fleet renewal and radical innovation, such as the introduction of more fuel-efficient aircraft with lighter composite structures; flight operational efficiency, including optimized flight paths and lighter onboard equipment; accelerated uptake of sustainable aviation fuel (SAF); and additional operational and value-chain measures, such as more efficient ground operations and cooperation with suppliers to lower emissions (KLM, 2023; ACC, 2024).

KLM's 2024 Annual Report further shows how this transition is embedded in day-to-day performance management. The Back on Track program groups a set of measures to improve profit, increase cost efficiency and stabilize operations in the short term, so that the airline can close its funding gap and reach a structural profit margin target in the second half of the decade (KLM, 2024). At the same time, the report stresses the need to reduce disruption, increase fleet availability and deal with tight labor markets and strained supply chains. In other words, operational robustness, financial discipline and sustainability ambitions are closely connected: improvements in one area cannot come at the expense of the others for long. This creates a context in which questions about reliability, cost and environmental impact of aircraft maintenance and part management become strategically relevant.

Figure 1: KLM Purpose, Vision & Strategy (KLM, 2024)

2.2 THE OPERATION BUSINESS MODEL

KLM E&M's main customer is Fleet Services, who they offer three products: their three departments.



AFI KLM E&M is the Air France–KLM MRO business: it keeps aircraft airworthy for the Group and for third-party airlines by combining engineering, line maintenance, base/airframe and engine work, plus part repair and supply, all organized around a logistics network.

How the network works is mainly logistics and distributed capability. They run a global MRO operation with 20+ maintenance facilities and a parts services network built around 8 regional logistics centers positioned in major hubs across Europe, the Americas, the Middle East and Asia. Those logistics centers are linked by daily flights, and they can deploy "advanced inventories" close to an airline's bases to shorten turnaround times (TAT) and reduce logistics cost, while providing 24/7 AOG (Aircraft On Ground) support for urgent disruptions. Recent industry survey results show material-cost inflation around ~8% in the past year, with continued inflation expected, **reinforcing cost pressure and parts availability are now structural rather than incidental (Oliver Wyman, 2024).**

Although AFI KLM E&M is a large maintenance group, the **sixth largest in the world** (Spherical Insights, 2025), the main purpose of the maintenance operation is not to maximise maintenance revenue, **but to keep the fleet airworthy and available to fly.** This way the airline can operate its network and sell tickets. Because Air France-KLM also provides maintenance services to other airlines, it accounts for **6.6%** of Group revenue (Aircraft Maintenance | AIR FRANCE KLM, n.d.).This context matters because downtime is where the pressure sits: there is no single daily cost for an Aircraft on Ground (AOG) event, since it depends on the technical issue, required parts, logistics lead times, labor, lost utilization and passenger disruption. But industry estimates indicate that an AOG can already be in the range of **$50,000–$150,000 per flight hour or more**, and can escalate quickly when disruption lasts multiple days or involves major parts and recovery operations (Aircraft Commerce, 2021). **Therefore, maintenance revenue should be regarded as context rather than the main sucess metric.**

figure 2: Global MRO Network Airfrance Industries KLM Engineering & Maintenance (KLM E&M, 2023)

2.3 THE OEM – MRO POWER DYNAMIC

The OEM, Original Equipment Manufacturer e.g. Boeing/Airbus) versus MRO, Maintenance Repair Overhaul (e.g. KLM Engineering & Maintenance) relationship is going though a structural power shift in which **value moves from independent MRO providers toward OEM-controlled aftermarket services.** This shift is enabled by "strategic bottlenecks": OEMs retain control over co-specialised assets required for compliant maintenance, such as IP (intellectual property), technical documentation, proprietary diagnostics and software, certified spare parts and the contractual terms that govern access. When replacements are constrained, OEMs can dictate service conditions and limit the strategic autonomy of independent MROs, even when MROs still execute the work. **According to an industry survey, the expansion of OEMs in the aftermarket is a particular worry for MRO respondents.** Carbon emissions reduction and reporting, while not yet top of mind, is emerging into view (Oliver Wyman, 2024).

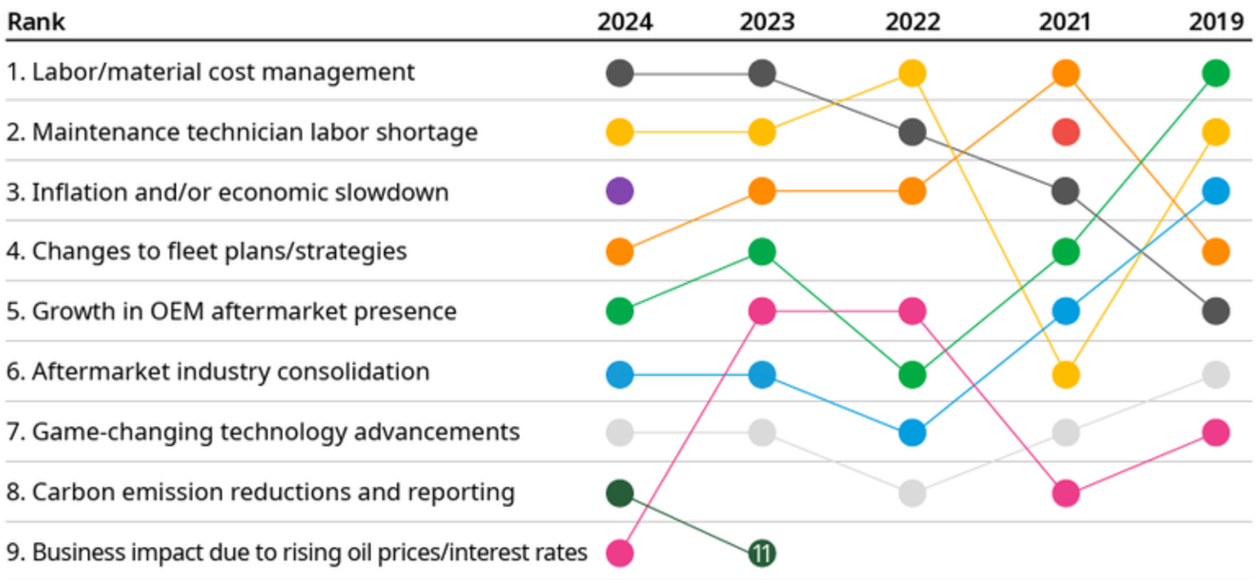


Figure 3: Top disruptors for aviation MRO 2019-2024 according to an industry survey done by Oliver Wyman (2024)

Hallensleben et al. distinguish OEM bottleneck exploitation strategies based on how tightly the OEM controls access (from contractual to equity-based governance) and how much value co-creation is offered to partners. Three primary strategies are described in figure 4.

OEM bottleneck strategy	What the OEM does (control point)	Effect on MRO option space
Controlled expansion	**High relational control** via shared ownership and governance; critical assets stay inside the OEM's extended boundary	*Secure access and workload, but the MRO becomes organizationally embedded and loses strategic autonomy*
License networks	**Contract-based, conditional access** to IP/materials for fees; OEM stays gatekeeper by controlling licensees and spare-part terms	*You can participate, but the relationship stays transactional; autonomy is limited and pricing power remains with the OEM*
Exclusive partnerships	**High control over a single partner** via an exclusive license	*Strong lock-in and path dependency; high risk of stranded capability without negotiated rights*

Table 4: OEM bottleneck exploitation strategies

Where circularity and this thesis adds value for MRO response options to OEM's

This thesis adds most value to the response space in figure 4 **where mobility can be increased through operational capability and ecosystem governance, rather than through contract renegotiation alone.** The contribution is practical: it builds an internal mechanism to (1) make routing outcomes comparable, (2) identify repeatable value-loss patterns, and (3) prioritise where repair routes should be stabilised, scaled, or developed so that "alternative repairs" become usable capacity instead of one-off exceptions.

- **License networks:** This thesis is most relevant here, because expanding compliant alternatives only works when routing outcomes are consistently recorded and recurring single-source losses become visible, so repair development and sourcing can be targeted rather than reactive.
- **Exclusive partnerships:** This thesis helps by making repair capability repeatable and governed instead of person-dependent, which reduces lock-in risk and keeps know-how transferable beyond one contract, time window, or partner setup.
- **Controlled expansion** This thesis supports this strategy indirectly by producing the evidence base to decide where dependence is structural and where building alternative repair capacity would actually reduce operational risk, which strengthens the case in negotiations and alliances even if the bottleneck cannot be removed locally.

2.4 STRATEGIC DESIGN IN AN AVIATION MRO CONTEXT AND ITS UNIQUE CHALLENGES

So in conclusion, what context factors should be taken into account throughout the design process?

Aircraft MRO is a regulated and safety-critical environment. Many choices are fixed by airworthiness requirements, certification and documentation rules, warranty handling (Liangrokapart & Sittiwatethanasiri, 2022). This means that even when a part is technically repairable, it can still be blocked by contractual limits, missing manuals, or the lack of an approved repair route (EASA, 2023).

MRO is also driven by operational pressure. Availability and turnaround time dominate daily priorities, and routing choices are made under time constraints, volatile lead times, and capacity limits. This pushes teams toward decisions that are fast and reliable, even when that can increase scrap or reduce value retention over time.

A third challenge is the organisational reality: **expertise is deep and specialised**, and people quickly test new ideas against exceptions, edge cases, and process detail. In the circularity indicator workshop, circularity concepts did not naturally translate into “how do we decide differently”; the discussion shifted to terminology and practicality first. That is not resistance to sustainability itself, **but a signal that the logic must fit existing decision routines, ownership, and data realities before it can land.**

How does a strategic designer navigate this challenges?

A strategic designer works in the front end of innovation, where the direction is still unclear and the main risk is solving the wrong problem. **The value is in structuring complexity into a shared understanding: clarifying what the real challenge is, for whom it matters, and what “better” would look like in practice.** This is different from designing a single product or process improvement, because the work starts before requirements are fixed and before solutions are chosen.

In practice, strategic design combines research, synthesis and facilitation to bridge people, operations and strategy. It brings different perspectives together, surfaces assumptions, and translates abstract ambitions into language that teams can discuss and use. It also helps to connect long-term goals to near-term reality by making trade-offs explicit and framing decision-making in a way that fits organisational constraints. The outcome is not a finished implementation, but a clear direction and foundation that makes later development and adoption more realistic and aligned across stakeholders.

Challenges and the role of the Strategic Designer

Hard boundaries (regulated, safety-critical)

- Regulation, certification, documentation
- Warranty/OEM constraints, approved vendor lists

translate boundaries into clear decision space. Make non-negotiables explicit so innovation starts from what is actually possible.

Operational pressure (availability-driven)

- TAT (turn around time), lead-time volatility, capacity limits
- Incomplete info at decision moments

frame decisions around the moments that matter. Simplify complexity into usable language and shared reference points that hold under time pressure.

Deep expertise & traditional culture

- Specialized knowledge, strong mental models
- New ideas stress-tested on exceptions; innovation pushback

facilitate alignment across roles; create shared understanding and legitimacy by making experts co-owners of the direction, not "reviewers" of a finished idea.

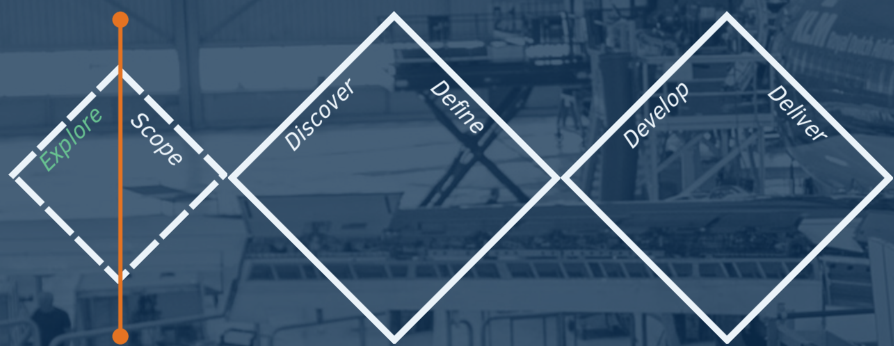
III

Strategic Framing

Defining focus and where this thesis adds value

TAKE AWAYS FROM EXPLORE

1. *MRO choices are shaped by non-negotiable constraints and availability pressure.*
2. *The shift in OEM - MRO power dynamic threathens the strategic autonomy of MRO's*
3. *A bounded real workflow is needed to stay credible and avoid abstraction.*



GOAL

Narrow the project to a feasible and impactful focus where circular value retention can be studied and translated into usable direction.

FOCUS

1. Where can this thesis add value, given time, access, and boundaries?
2. What will be included, and what will be left out?
3. Which case best represents the decision challenge while staying manageable?

METHODOLOGY

1. Explorative interviews
2. Shortlisting based on feasibility, viability and desirability of the scope

3.1 PROBLEM DEFINITION: CIRCULAR LOSS IN AVIATION MRO OPERATIONS

Based on the context and challenges, what will this thesis address?

Maintenance, Repair, and Overhaul (MRO) operations manage a large share of the material flow within aviation and therefore hold significant potential to reduce waste and extend lifecycles, provided safety and regulatory requirements are met. **These operations are an area with clear potential for applying circular economy principles**, because circularity is not only a technical question, but a question of how decisions are made under constraints in daily operations.

Early project work showed that circularity is not yet a shared working language in day-to-day MRO decision-making. Before circular value can be weighed alongside other factors, it must first be translated into clear, usable decision principles that fit this operational context, its data realities, and its boundary conditions. **This is why the work in this thesis starts with understanding the operation as it is**: how parts move, where decisions are taken, and which constraints and information conditions shape outcomes. Without a deep operational understanding, circularity risks staying generic, triggering debate on exceptions, or producing concepts that do not fit the way teams work.

After that, it is **necessary to review how circularity has been conceptualized, operationalized and measured across existing research.** Circularity and circular business models have been widely explored in manufacturing and product design, but application in this regulated, safety-critical aviation MRO environment remains poorly defined. A comprehensive literature review is therefore required to explore theoretical perspectives, identify gaps in current understanding, and establish a foundation for developing a definition and measurement approach that suits the aviation MRO context.

Operational Deep Dive: Salvation & Warranty as Grounded Case

To avoid designing in abstraction, this thesis is grounded in a deep dive into a real routing context within KLM E&M. A bounded operational case makes it possible to give insights into decision points, ownership and information conditions. It also allows to identify where value is retained or lost in practice. **This approach ensures that later design directions are rooted in the reality of MRO work, rather than assumptions about what "should" happen.**

To find this bounded operational case, explorative interviews were held with the Program Manager of the Technology Hub and the Team Leader Material & Equipment Supply Chain, a division of Airframe. This interview can be found in appendix O.

Salvation & Warranty (S&W) was selected as the grounded case because it is a relatively smaller and more contained part flow compared to the full MRO system of E&M, while still representing the core challenge of routing decisions under constraints. In addition, the workflow deals largely with non-critical parts, often plastics, where repair is more feasible and where value retention discussions can be grounded in practical options rather than immediately being blocked by safety-critical limitations. Because this is a hub where parts parts are checked and rerouted to different places, this is internally called: Checkpoint Charlie (see figure 5).

Because Salvation & Warranty is a 'hub' where a large volume of parts flows through, **it contains multiple decision moments where circular value is either retained or lost.** In practice, the limiting factor is not intent, but whether outcomes are captured consistently enough to become comparable and reviewable under operational pressure. This makes S&W a high-leverage and suitable entry point to study how circular value retention can play a role in MRO decision-making while keeping the scope manageable for the graduation project.

Because this workflow is shaped by scattered or tacit gate rules and ownership that are not visible from one system view, **the as-is routing is reconstructed through cross-role interviews and iterative validation rather than document analysis alone.** The full routing description and insights can be found in Appendix G.

Figure 5: Salvation & Warranty (Checkpoint Charlie)

3.2 RESEARCH QUESTIONS

Building on the choice to ground this thesis in the Salvation & Warranty routing case, the research questions below structure the work from describing how routing decisions are made today to developing a practical way to strengthen circular value retention within those decision moments.

Main research question: How can KLM E&M integrate circularity into aviation MRO decision-making to retain value in parts?

SQ1: Context and current system *How does the Salvation & Warranty process route dismounted parts today, and which actors and constraints most strongly determine the feasible routing options?*

SQ2: Decision funnel (as-is) *What are the key decision gates in this routing process, and what practical pass/fail logic is used to move parts between routes?*

SQ3: Information conditions *Which information is actually used at each gate, and how do gaps in timing, ownership, and quality push decisions toward scrap/replace rather than value retention?*

SQ4: Prioritization and organizational drivers *How are repair or alternative routing options selected, approved, and scaled within E&M, and what organisational incentives and constraints shape those choices?*

SQ5: Defining and operationalizing circularity *What does "circularity" mean at part level in this context, and how can it be made operational through indicators and an implementation roadmap that fits daily work?*

The next chapter establishes the conceptual foundations needed to interpret these routing outcomes through circular economy theory, so that later chapters can translate the case findings into an operational definition of circularity and measurable decision signals that fit the realities of MRO work.

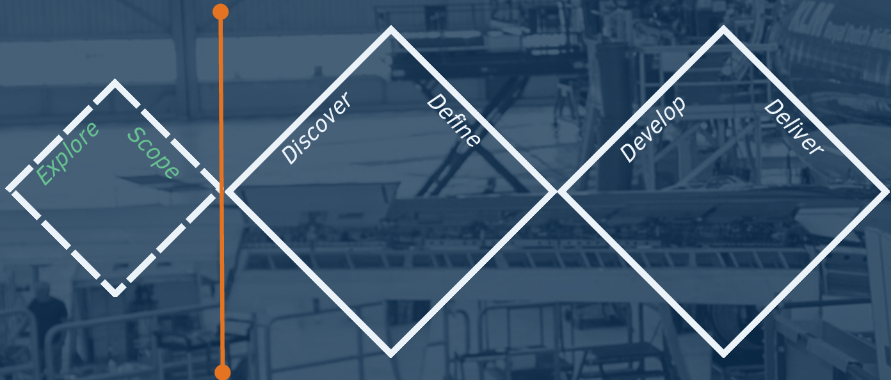
IV

System Mapping

Reconstructing the current decision system that leads to value loss

TAKE AWAYS FROM SCOPE

1. *The S&W case and boundaries are fixed, so analysis can go deep without drifting.*
2. *The focus is on decision-making in routing, not on redesigning the full operation.*
3. *Evidence of value loss must be strong enough to support later design choices.*



GOAL

Build a baseline of how parts are routed today, including gates, ownership, information inputs, and constraints.

FOCUS

1. Explore circular theory in order to ask more focused question when discovering part routing
2. How does the routing actually work step by step?
3. Where are the decision gates, and who owns them?
4. What information and constraints steer outcomes at each gate?

METHODOLOGY

1. Circular literature review
2. In-depth interviews with supply chain analysts and repair developer
3. Exploring & describing of physical places at Schiphol-Oost
4. Reviewing of internal documents
5. Process-mapping of routing
6. Interviews are used as a reconstruction method

4.1 KEY FINDINGS CIRCULARITY LITERATURE REVIEW AND THESIS IMPLICATIONS

To do a focused discover phase of the Salvation & Warranty routing, a literature review on circular theory was done and can be found in appendix E. Having this knowledge in advance allows for asking relevant questions and better scoping while conducting interviews and research. The key findings are the following:

Circular economy literature defines circularity as keeping products, parts, and materials at their highest possible value for as long as possible, through strategies such as maintenance, reuse, repair, refurbishment, remanufacturing, and recycling. The central takeaway is that circularity is not only about reducing waste, but about retaining functional and material value across multiple lifecycles.

The most useful translation for this thesis is the R-framework (figure 6)**:** it provides a clear hierarchy of value-retention strategies, where higher-level loops retain more value and lower-level loops imply higher losses. This matters because it turns circularity into something that can be described consistently and compared across outcomes, rather than remaining an abstract sustainability ambition. In an aviation MRO context, **this enables circularity to be expressed as a part-level outcome of a routing decision:** whether a part is retained through repair/refurbishment or exits into low-value routes.

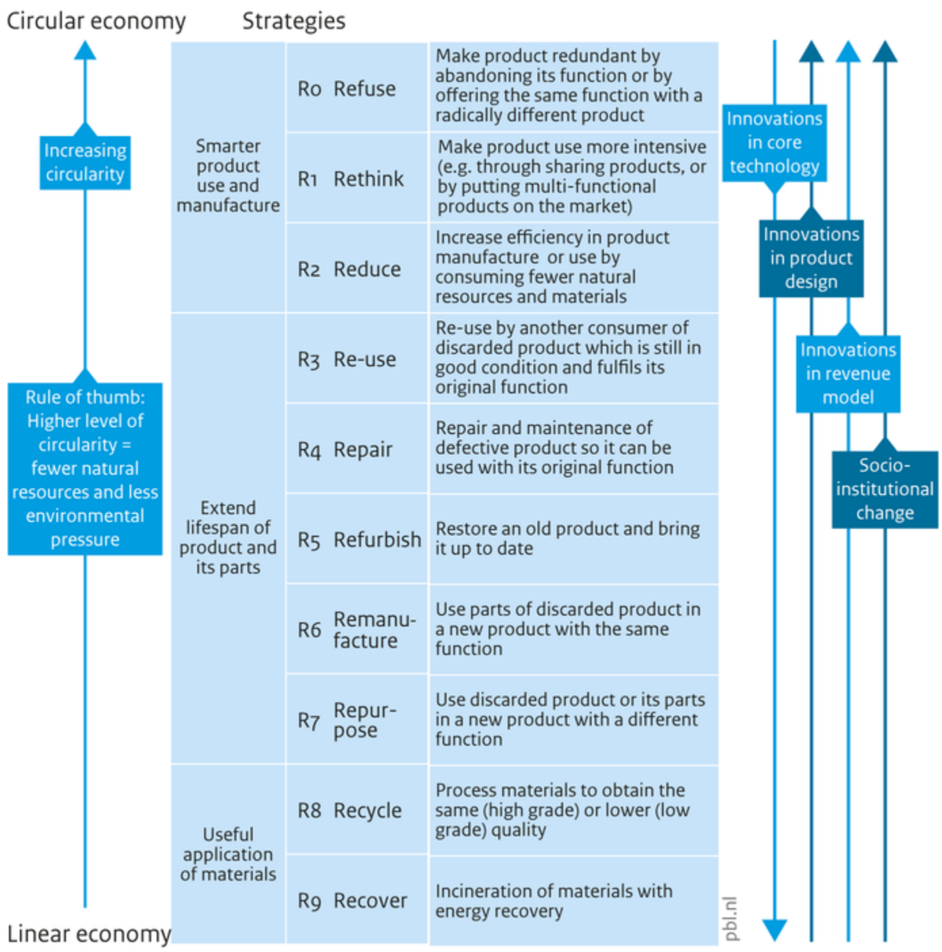


Figure 6: The R-ladder (Potting et al., 2017)

Circularity in aviation MRO is operationally constrained. MRO organisations operate downstream with limited design freedom and must work within safety, airworthiness, and contractual conditions. Circularity therefore cannot be implemented by redesigning the product, but by redesigning the decision logic that governs how parts are routed and retained in circulation wherever feasible.

The relevant unit of analysis is not "the product lifecycle" but the routed part moving through gates. Many circularity metrics assume full lifecycle data, stable material inventories, or design control, which do not match day-to-day maintenance decision-making. The practical need in MRO is a way to express circular value in terms that fit how decisions are made: comparing repair routes, weighing stock and lead-time risk, and trading off short-term operational impact against long-term value retention.

This section therefore positions the R-framework as the conceptual backbone for the thesis: it provides the outcome language needed to read MRO routing decisions as circular value retention choices, and it justifies why the thesis focuses on part-level decision moments, measurable outcomes, and implementable decision signals rather than on product redesign or full lifecycle accounting.

4.2 PART ROUTING AND MAPPING OF THE SUPPLY CHAIN

Within KLM E&M, removed parts do not follow a single path. After dismount, parts move through a routing system of checks, decisions, and handovers that determine what happens next: return under warranty, repair (existing or newly developed), reuse, storage, or disposal. **This routing is where value retention is decided in practice**, because each decision moment either keeps parts in a high-value loop or pushes them to lower-value outcomes.

As introduced at the strategic framing, Salvation & Warranty functions as a central hub in this routing. Internally, this hub is referred to as Checkpoint Charlie . It is the point where parts are checked, classified, and redirected to the appropriate next step, **making it a natural place to observe how decision logic and information conditions steer outcomes without redesigning the wider MRO system.** The routing provides a practical lens to study decision-making under real constraints: time pressure, information quality, contractual limits, and operational priorities.

In this thesis, the routing is used as an analytical frame rather than a process manual to improve. The goal is to make the decision structure visible: which gates exist, what triggers them, what information is required, who owns the decision, and what the typical constraints are. This structure makes it possible to compare cases consistently and to point out where avoidable value loss happens, without getting stuck in exceptions or local workarounds.

Creating a routing schematic supports this in three ways. First, it shows a single overview of the decision points and handovers, so choices become traceable. Second, it makes ownership explicit, which helps explain why some issues persist (for example when information is missing or responsibilities are split). Third, it connects routing outcomes to value retention: the route a part follows is the practical expression of whether value is retained at part level or drops to material-level outcomes.

Each step in the part-routing was mapped systematically, based on the R-level framework. Examples of each layer's activity and circular value can be seen in figure 6. Due to operational constraints, not every R-level exists in this operation. For example R0/1/2 are related to the production of the part. However due to the role as maintenance operation, E&M has no say in production in this and these levels where disregarded.

The part routing was created using a decision tree to see where and how circular value is lost throughout the process. In Appendix G an overview can be found of each step, describing the aspects as seen in the example of table 7.

The next section therefore walks through the routing step-by-step, using the schematic to describe each gate, its input conditions, and the typical reasons parts move to different outcomes.

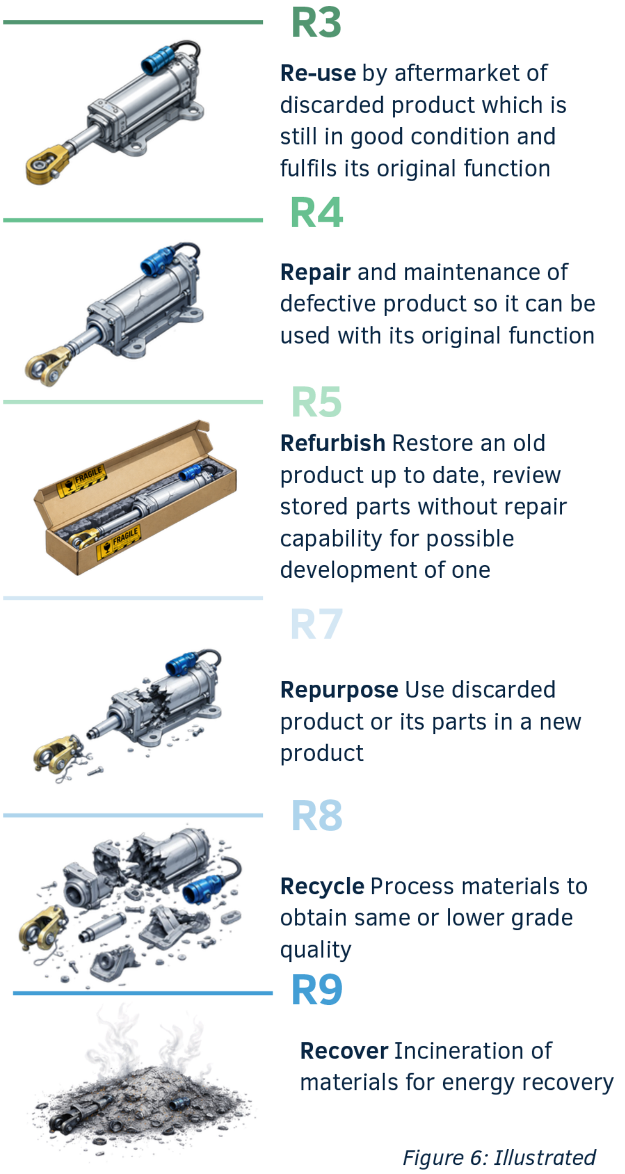
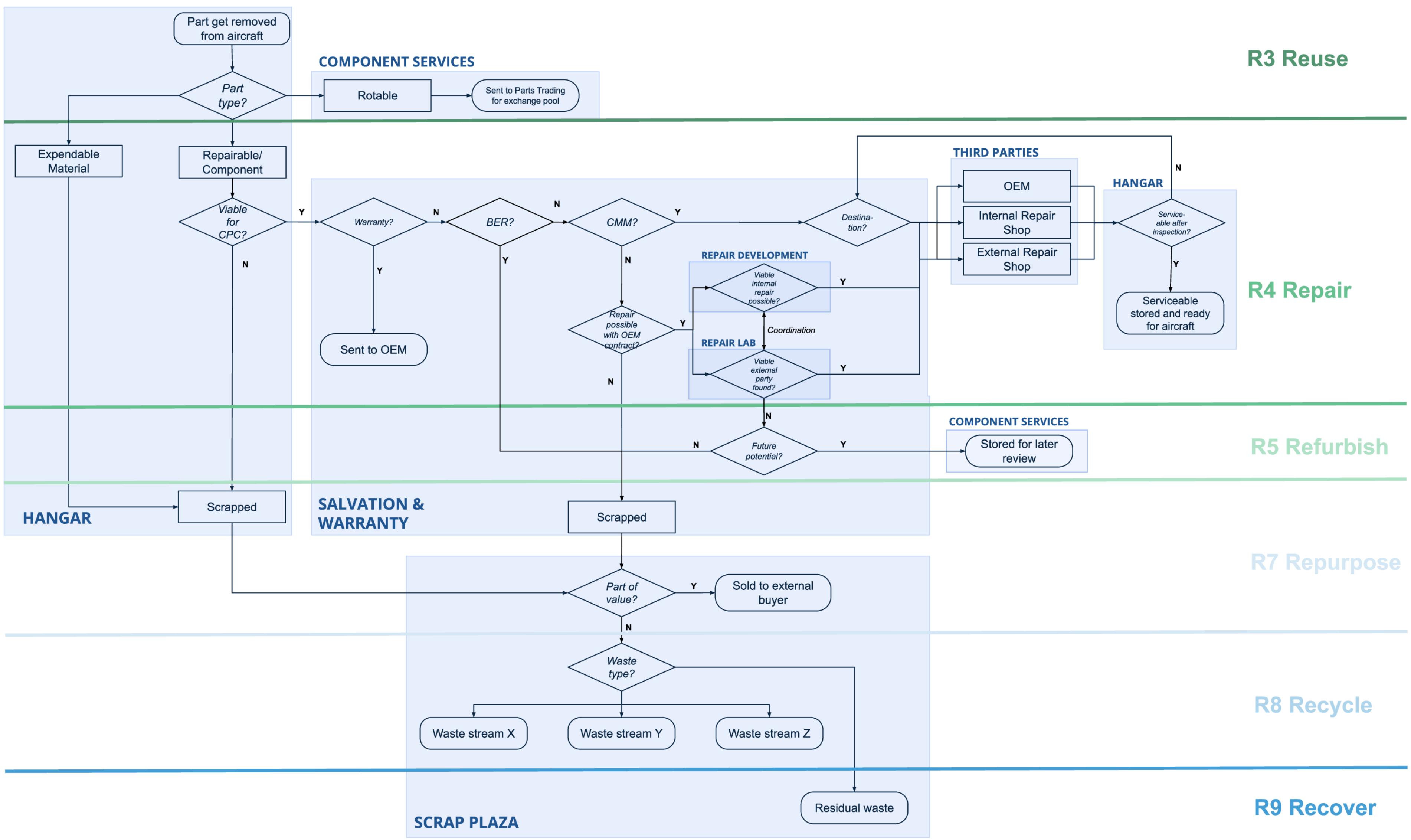


Figure 6: Illustrated examples of R-levels

Node	*Part type?*
R-Level	3
Ownership	Aircraft Mechanics
Information input	• # part cycles • Part service time • Defect observed
Criteria	E&M Material Classification (Interview Team Leader MEF supply chain appendix M)
Drivers	• Safety/airworthiness • Stock availability of parts • Mechanic expertise
Constraints	• Time pressure due to Aircraft TAT deadlines • Missing part information leads unclear routing decision and therefore unnecessary scrapping

Table 7: example of description of decision gates



Simplified version of supply chain with corresponding R-Levels for illustration

4.3 ROUTING ANALYSIS TAKE-AWAYS

Value retention is mainly shaped by a small set of gates with hard constraints
The routing functions as a decision chain: parts are filtered through checks that progressively narrow what is allowed and practical. A large share of outcomes is set by “hard lanes” such as warranty ownership, OEM authority, and contract limits, which can override local preferences even when alternative routes exist.

Within that chain, Salvation & Warranty (Checkpoint Charlie) is the central convergence point after removal: it is the first structured decision gate where multiple constraints and hand-offs come together and where downstream outcomes are effectively committed.

Avoidable downflow happens early due to time pressure and information quality
The mapping shows that the earliest steps are structurally high-risk for value loss. Tagging and classification at removal strongly steer what enters Salvation & Warranty versus what is discarded. Under time pressure and limited visibility of “worth,” parts that could have been repaired can be routed out too early.

This pattern matters because once a part misses the repairable stream, later gates cannot recover product-level value. The effect is not one “wrong decision,” but a repeated bias toward fast disposal when information is incomplete and the operation is under pressure. This makes value retention a steering problem: without consistent outcome capture at these early gates, improvement stays case-by-case and cannot be directed.

Repair outcomes depend on capability and learning, not only technical feasibility
Even when a part is repairable in principle, repair is not guaranteed. The routing contains recurring “capability blockers”: missing or unclear manuals/repair routes (the CLINIC stream), limited development capacity, and contract restrictions that limit third-party or in-house repair.
In addition, the mapping highlights weak learning signals: limited forward visibility on scarcity, unreliable visibility of repair capability in systems, and limited feedback on repaired-part performance. This makes it difficult to improve routing decisions over time, especially for borderline cases.

Conclusion and transition to the next section
After mapping the full routing, the scope now narrows to decision-making within Salvation & Warranty. This is where the key nodes that steer outcomes come together: intake, CMM verification, the warranty check, BER, and the hand-offs to Repair Development and the Repair Lab. Because these gates sit at the convergence of constraints, information, and ownership, leverage on outcomes is highest here—either preserving higher-value outcomes (R4 repair) or allowing downflow to R5 refurbish or material routes.

The detailed mapping shows where and how parts fall to lower R-levels, but it does not yet explain how these patterns relate to broader circular strategies and circular business models.

The next chapter therefore reinterprets the routing findings through circular economy frameworks to sharpen the problem framing and design requirements.

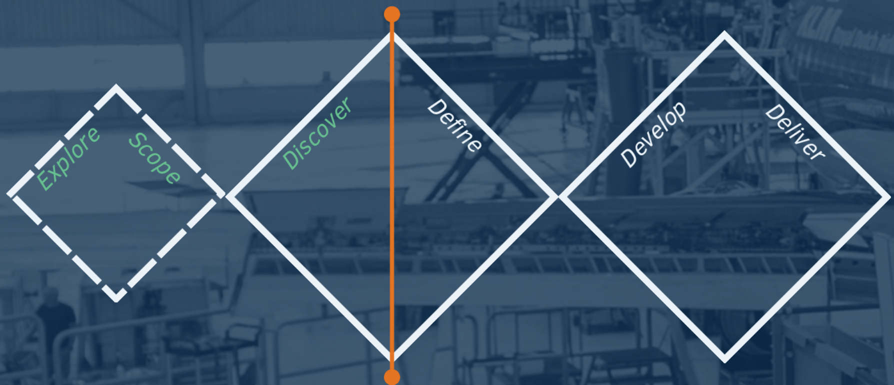
V

Decision Framing

Turning findings into a clear problem definition and design requirements

TAKE AWAYS FROM DISCOVER

1. *Outcomes are shaped by a small set of decision gates under hard constraints.*
2. *Information quality and time pressure steer avoidable downflow.*
3. *Ownership and capability gaps explain why repair routes are not triggered consistently.*



GOAL

Translate the Discover findings into a sharp problem definition and a set of design requirements that guide what must be developed next.

FOCUS

1. What is the real problem behind the observed value loss patterns?
2. Which requirements must any direction satisfy to be usable in daily work?
3. What should be treated as non-negotiable versus changeable?

METHODOLOGY

1. Framing findings through circularity theoretical concepts
2. Synthesis of findings into themes
3. Translating findings into requirements

5.1 LITERATURE SYNTHESIS CIRCULARITY IN MRO CONTEXT

The previous section established the operational problem: routing decisions are shaped by hard constraints and incomplete information, which often makes scrap or new-buy the safest outcome even when value could have been retained. This iterative literature review is therefore not included to restate circular economy theory, but to extract what is directly useful for this context: which circular mechanisms are realistic in aviation MRO, and what they imply for decision-making and governance in E&M. The full review can be found in appendix H.

Take-aways:

1. Circularity theory starts at design of a product, but E&M operates downstream: parts are inherited and regulation/documentation limits what can be changed, **this makes circularity in MRO constricted**
2. In this context, **the main circular lever is not "better design," but how far repair can be pushed within approved routes.** Multiple certification pathways for alternative repairs already exist, but they are not scaled across enough parts, so scrap/new-buy still happens in cases where a repair route could be feasible.
3. Bocken's "slow–close–narrow" framing translates into an MRO reality: **slowing** = extending functional life through repair/refurbish; **closing** is limited by safety/traceability (so value retention is more about keeping functional value in use than material recovery); **narrowing** = efficiency that only matters when it supports keeping parts in use longer.
4. In MRO, these circularity often occurs as a side effect of cost, lead time, and reliability pressures, not as an explicit strategy. **The challenge is therfore recognizing and measuring circular value creation as something to steer.**
5. Geissdoerfer extends this to the business model level: **circularity only gains traction when it is part of value creation/delivery/capture**, and most organizations end up in hybrid logics where linear and circular value mechanisms coexist.
6. **E&M fits that hybrid pattern:** linear imperatives (availability, compliance) remain non-negotiable, while repair/reuse already create circular value "by accident" when they are cheaper, faster, or necessary under scarcity. It becomes "circular" in an operational sense only when made intentional and supported by an adapted network.

In conclusion, the literature shows that circularity in **MRO is primarily a value-retention challenge**: slowing loops through repair and reuse is the main lever, while closing loops through recycling remains secondary and constraint-driven. For E&M this means circularity only becomes implementable when it is translated from theory into operational choices that can be steered, linking routing outcomes and repair capability decisions to explicit goals and measurable trade-offs.

The next section therefore translates these insights into the circularity goals and selection criteria used in this thesis.

5.2 CIRCULARITY GOALS

Geissdoerfer states that **circularity is not a loose set of green initiatives but a business model logic that must be supported by an operational network capable of retaining value.** Geissdoerfer also states **most firms operate in a hybrid state where linear and circular logics coexist rather than one fully replacing the other.** Building on that, the following objectives translate those abstract logics into the aviation MRO context by mapping them onto the concrete priorities inside KLM E&M. The spectrum positions “pure linear” and “circular-by-design” at opposite ends and then locates today’s practice, plus a feasible near-term target, on a 1–7 scale for each dimension. Each row expresses a strategic tension that plays out in day-to-day decisions. **The point is not to say current practice of being too linear. The point is to expose where circular value is already being captured indirectly** (e.g. via repair to avoid lead time and procurement cost), **and where it is lost and where incremental rule changes could systematically shift more parts toward higher-value loops without undermining airworthiness or availability.** In other words, it operationalizes the hybrid logic for E&M instead of describing it in general terms. The full reasoning can be found in appendix I.

Service objective

prevent AOG with proactive stock planning and repair to keep inventories complete.

Maximize continuity and availability.

Maximize lifecycle value.

integrating simple value retention indicators

Reliability Logic

creating visibility on where value is lost.

Prioritize reliability even if resource-inefficient.

Deliver reliability through stewardship.

reliable histories, condition feedback, and explicit ownership of a part

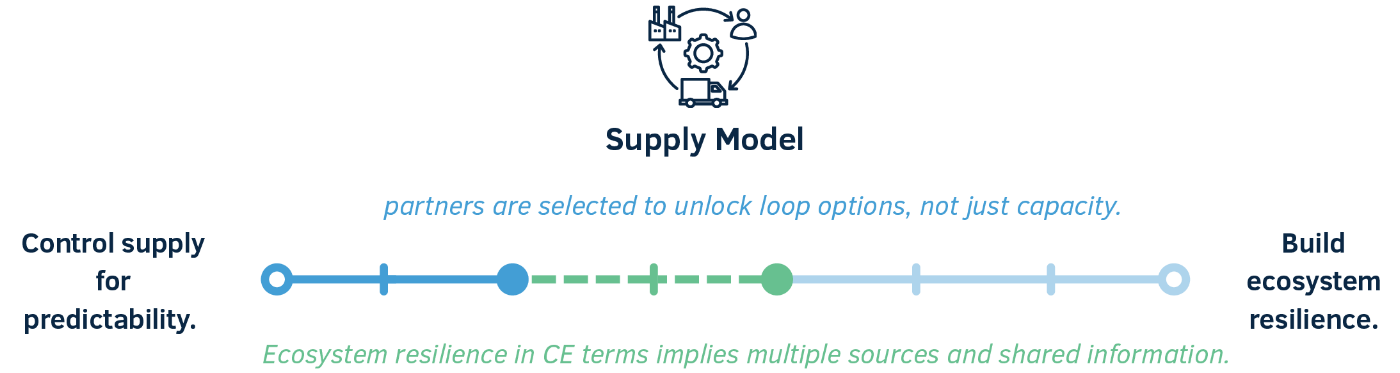
Cost Logic

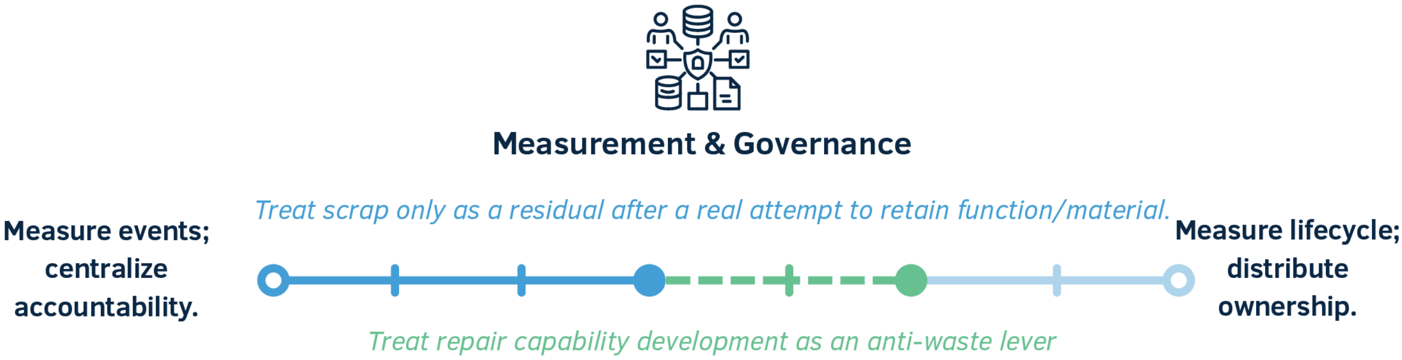
avoided procurement, lead-time risk, and service life extension.

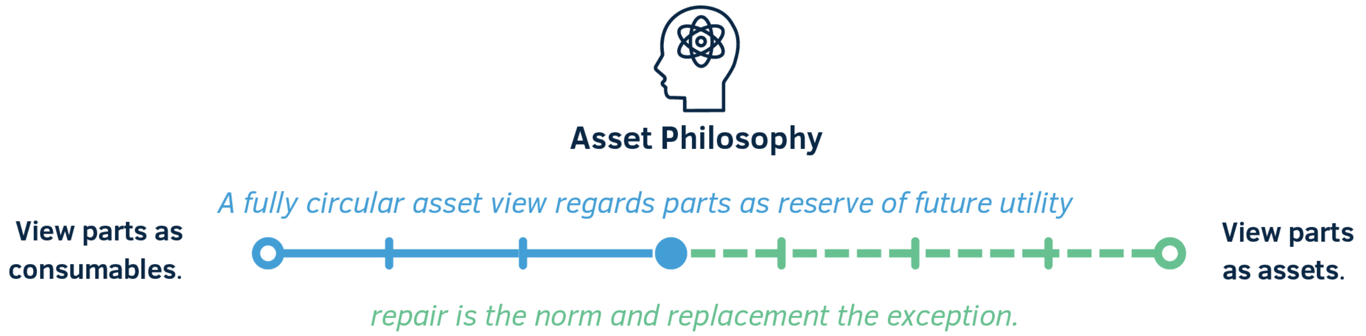
Optimize cost per event.

Optimize lifecycle cost via value retention.

value capture must reflect loop benefits to change choices







Conclusion

This spectrum makes three things explicit. First, **E&M is already partially circular in practice,** but mainly where continuity, cost avoidance, and stock protection make repair, reuse, and life extension economically attractive. That means value retention is present, but it is treated as situational and handled largely through local expertise rather than embedded policy.

Second, **shifting toward a more circular position does not require a philosophical reset. It requires formalizing what is already done in pockets**: naming ownership of stock and afterlives, quantifying value retained alongside event cost, creating intermediate "hold and reassess" states instead of defaulting to scrap, and normalizing multi-path sourcing instead of assuming single-OEM supply.

Third, **the critical leverage point for this shift sits inside the routing decision process itself.** This is where eligibility is judged, parts are directed into routes, costs and risks are weighed, and outcomes are either logged or disappear in case-by-case reasoning. If circular retention is going to move from incidental to intentional, it will start at these decision moments. The next step is therefore to go inside the routing process, treat each decision point as designable, and determine which rules, ownership definitions, and simple metrics need to change so that the higher-loop option becomes the default rather than the exception.

5.3 SUBQUESTIONS REVIEW

With these conclusions, the process is further in answering the main questions: How can KLM E&M integrate circularity into aviation MRO decision-making to retain value in parts?

The sub questions were stated as the following:

- **SQ1, Context and current system:** How does the Salvation & Warranty process route dismounted parts today, and which actors and constraints most strongly determine the feasible routing options?
- **SQ2, Decision funnel (as-is):** What are the key decision gates in this routing process, and what practical pass/fail logic is used to move parts between routes?
- **SQ3, Information conditions** Which information is actually used at each gate, and how do gaps in timing, ownership, and quality push decisions toward scrap/replace rather than value retention?
- **SQ4, Prioritization and organizational drivers:** How are repair or alternative routing options selected, approved, and scaled within KLM E&M, and what organisational incentives and constraints shape those choices?
- **SQ5, Defining and operationalizing circularity:** What does "circularity" mean at part level in this context, and how can it be made operational through indicators and an implementation roadmap that fits daily work?

The first diamond has addressed SQ1–SQ4 in the following way:

For SQ1, the Explore & Discover phases mapped how dismounted parts are routed through MEF with Salvation & Warranty as the central hub, which roles are involved, and which contractual, technical and regulatory constraints shape their decisions. **The result is an overview of routing options and a stakeholder/constraint map that anchors the thesis in a concrete part of E&M's operation.**

For SQ2, semi-structured process interviews, document analysis and detailed process mapping produced a gate-by-gate description of the routing. Each node specifies the decision question, pass/fail routes, criteria and thresholds, required inputs, constraints and responsible owner. **Together with the routing schematic and node tables, this reconstructs the decision funnel that routes parts to repair, reuse, resale, stock or scrap.**

For SQ3, the same analysis identified which information is required and which is actually available at each gate. This exposed structural gaps: fragmented visibility on recurring scrap patterns, limited forward insight into scarcity, weak feedback on repair performance and circular value, and dependence on historical or incomplete data in key gates such as BER. **These information conditions explain why, decisions tend to favor short-term cost and availability over long-term value retention.**

For SQ4, interviews with the stakeholders, combined with review of KPIs, mapped how repair development candidates are selected and which trade-offs dominate. **The analysis shows that day-to-day routing and escalation are driven by a narrow operational and financial lens**: thresholds for Beyond Economic Repair, AOG avoidance, lead-time and price risk, development capacity constraints and OEM contract limits. Technical options for higher-value loops exist (the five routes for developing alternative repair capabilities), but they are triggered mainly by ad hoc signals such as noticed high cost or repeated scrap, rather than by systematic criteria embedded in the process.

Viewed through the circular spectrum and R-framework, these findings show a consistent pattern. **Circular outcomes already occur in practice, but they emerge as side-effects of decisions aimed at continuity, cost avoidance and stock protection.** Circularity is not defined or measured as a separate value dimension; there is no shared "asset philosophy" per part class, no standardized triggers that connect recurring loss patterns to new repair development, and no clear ownership for improving circular outcomes over time. Circular value is therefore determined by the existing routing and decision architecture, but remains largely invisible and unmanaged within it. This leads to the following restated problem definition:

KLM E&M already repairs and reuses large numbers of parts and technical routes exist to expand this further but much of that potential stays unused.

Parts move to scrap or low-value outcomes even when repair or reuse would have been possible, because the circular value of those options is not visible in the way decisions are framed.

The core problem is that the system lacks a clear way to make the long-term value of keeping parts in higher loops visible at the moment of routing. The design task is therefore to make circular value outcomes visible and comparable at routing moments so they can be governed and improved over time.

5.4 DESIGN REQUIREMENTS

Based on the findings and problem definition the key requirements for the design intervention can be formulated with findings that support the requirement *(in grey)*. These requirements translate the findings of the first diamond into concrete conditions that any intervention in the second diamond must satisfy. The full findings with their codes, themes and participants can be found in appendix P and Q

1 Objective: The redesigned decision logic must **treat parts as assets retained in circulation by default**, increasing the share of higher R-level outcomes wherever technically and contractually feasible and financially viable. Specifying when lower R-level outcomes are acceptable.

#4 "Repair development selection uses thresholds (usage frequency + part value), supported by SAP + shop input."

#5 "Fleet growth + many new part types → cherry-picking; higher thresholds push more parts straight to Scrap Plaza, reducing circularity and profit."

#23 "BER strategy is a leverage point; smarter scrapping should consider material type and embodied emissions."

2 Steering Trigger: The decision logic must include **clear signals and triggers that highlight structural value loss** and link these cases to available mechanisms for developing or sourcing alternative repair options.

#10 "MEF: strong inventory/vendor management but lacks visibility on scrap rates and repair success."

#27 "Indicator workshop: governance gaps (policy/ownership, parallel funnels, ad hoc triggers); Repair Lab capacity not steered by long-term value."

#3 "Clinic items: important to repair but blocked by missing manuals; Repair Development + Repair Lab try to unlock."

3 Governance & Traceability: Decision-making must be structured so that **routing outcomes are logged, traceable over time and clearly owned**, enabling systematic identification and follow-up of opportunities to keep parts in higher-value loops.

#27 "Indicator workshop: governance gaps (policy/ownership, parallel funnels, ad hoc triggers)…"
#9 "Intake is fragmented; need a supply chain analyst layer to pre-sort before repair development."
#11 "SAP does not reliably show repair capability; shared fields with Air France limit interpretability."

4 Boundary Condition: Circular value must be integrated alongside existing constraints of safety, airworthiness, contractual terms and availability, so that routing decisions remain compliant and operationally robust while making better use of repair and reuse potential.

#17 "Incorrect disassembly can void OEM warranty, changing feasible routes."
#6 "OEM vs third-party: OEM often far more expensive; contracts or lack of alternatives can force OEM route."
#20 "AOG avoidance makes stock and lead time central to routing."
#19 "AVL constrains which vendors can be used for repair."

5 Value Accounting: The process must make the financial and environmental effects of routing choices visible in a simple way, so that the retaining **circular value can be weighed explicitly** against other performance measures.

#22 "MEF: repair vs new rule of thumb (a confidental percentage) of new price; otherwise buy new."
#21 "CS: green supply chain focuses mainly on transport; internal CO_2 pricing used there today."

These requirements translate the first diamond into evaluation criteria for the second. In the Develop phase, they are translated into practical decision aids that fit the existing gate logic: **low-burden signals, basic templates, and ownership hooks that make value loss visible and traceable without breaking compliance.**

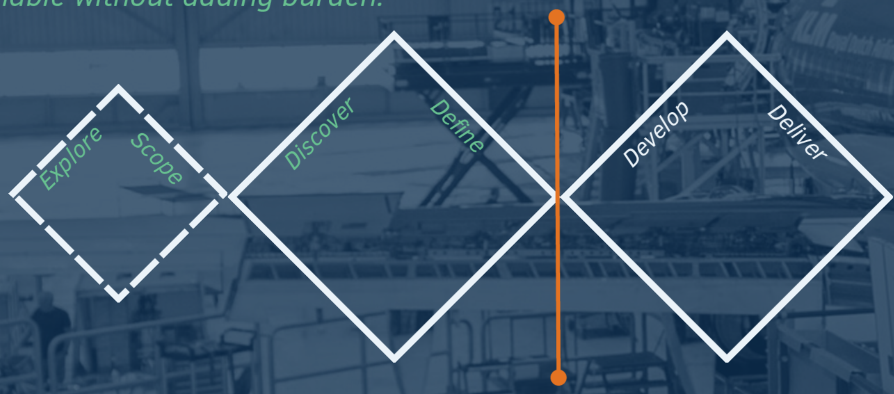
VI

Concept Development

Translating circularity into workable concepts for the operation

TAKE AWAYS FROM DEFINE

1. *The routing is formalized as a gate-based decision system with explicit owners, inputs, and hard constraints.*
2. *The problem is reframed as a visibility and governance gap: circular value is not comparable or steerable at the gates.*
3. *The remaining challenge is translation: create decision aids that make loss patterns visible and actionable without adding burden.*



GOAL

Turn the design requirements into concepts that merge circular value logic with how routing decisions are actually made in daily MRO work.

FOCUS

1. How can circular value be expressed in operational terms so that it is usable for people in the operation?
2. What information must be visible at decision moments, and what can stay out?
3. What concept forms can be used across roles?

METHODOLOGY

1. Ideation & validation of design interventions with different stakeholders
2. Refinement of concepts based on design requirements

6.1 Concept Direction Choice

With the Define phase concluded, the project moves from describing the routing problem to translating it into concepts that can be used at decision moments in daily MRO work. The Develop phase therefore started with an explicit choice of concept direction: selecting a format that could realistically be used, maintained, and owned.

Direction 1: Analytics-first (dashboard-only steering).
A reporting layer that visualises routing outcomes and loss patterns. This direction supports insight, **but on its own it does not reliably change what happens in the decision moment**. When information is incomplete or constraints appear late, decisions still default to the lowest-risk route.

Direction 2: Governance-first (procedure or policy change).
A formal update of work instructions to include circularity considerations. This direction can create legitimacy, **but it typically requires heavy coordination and can remain abstract if not translated into simple inputs and routines.**

Direction 3: Routine-first (meeting-embedded decision aid on repair capability choices).
A structured decision template embedded in the recurring Repair Development meeting, supported by shared outcome language and minimal logging discipline at the source. This direction creates a stable place of use, turns visibility into follow-up, and keeps the intervention aligned with existing decision routines rather than adding parallel processes.

Chosen Direction

For the rest of this thesis, concept development focused on the routine-first direction 3 because it anchors the intervention in an existing decision moment where trade-offs already happen, so circularity becomes a structured input to the choice instead of a separate analysis step that can be ignored.

Analytics (1) and governance (2) are treated as supporting elements, added only when they improve workability and do not increase overhead. The key pitfall is “process inflation”: if the structure feels like administration, use will drop and decisions will revert to ad-hoc judgement.

6.2 Circularity Indicator Workshop

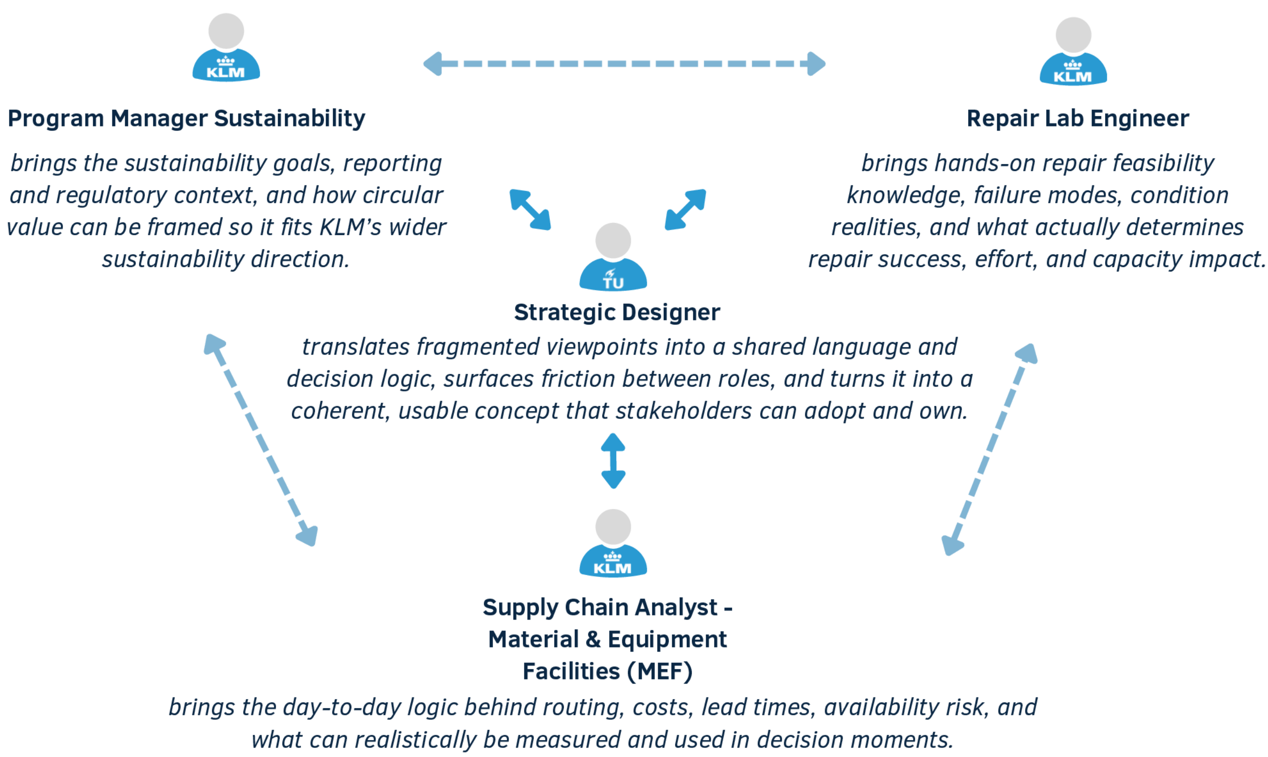
The next step was therefore to test potential indicators with stakeholders who each see a different part of the routing system, because the concept only works if those perspectives align on terminology, feasibility: what is realistic to measure and use.

A circularity indicator is a simple signal or label that shows where value is kept or lost when a part is routed (for example through repair, reuse, or scrap), At this stage the work focuses on the indicator logic and the minimum information needed at decision moments, not on building a dashboard.

so different teams can compare cases. An indicator workshop was held because KLM already has a lot of knowledge about parts and repair, but that knowledge is spread across roles and comes with different priorities and viewpoints, and this only works if those layers align. As a strategic designer, a co-creation workshop brings those perspectives into one conversation to surface friction early, shape a shared logic, and build ownership with the people who will later use it.

A co-creation workshop was held with a MEF supply chain analyst, the E&M sustainability program manager, and an engineer from Repair Lab. These participants were selected for their different backgrounds and therefore different perspectives on circularity, enabling a meaningful discussion. The goals of the meeting were the following, a description of the workshop can be found in appendix .

- Explore which indicators help people in the operation recognize circular value when deciding on the development of repair capabilities.
- Assess which of these indicators are feasible to integrate in the current operation.
- Identify a small set of promising indicators from a longlist created in advance based on data availability and circularity theory (see appendix O).



A longlist of candidate indicators was reduced using a C-Box (Impact × Effort) in figure 8 to arrive at a small, workable first set that fits existing Salvation & Warranty routines (van Boeijen et al., 2010, p. 125).

The outcome is a set of connected indicators. **R-level** is selected first because it creates a shared, comparable language for what happens to parts in routing, making value retention and value loss visible in a consistent way across cases. **'CO_2 saving with repair**' is selected as a directional sustainability signal that supports prioritisation without requiring full LCA at this stage. It helps distinguish where repair-versus-new likely matters most in terms of embodied emissions. **Circular Routing Ratio** is selected as the performance indicator that turns individual routing outcomes into a trend over time, enabling steering and monitoring improvement. In the circularity workshop, **repair performance** was first discussed as a repair-level measure, after which the focus broadened to part-level performance by comparing realised time-in-service against a benchmark, so that early discard becomes visible even when routing outcomes appear acceptable.

The sustainability lead's argument on material circularity leverage is captured indirectly through the CO_2 effect: parts with higher material mass and higher embodied impact tend to create larger avoided emissions when replacement is prevented. Rather than adding a separate material leverage KPI that would largely overlap and increase effort, this logic is incorporated through the CO_2 effect.

This also defines the dependency between indicators. CRR/R-ratio requires R-level implementation because it aggregates R-level outcomes over a period. Without stable R-level logging, CRR cannot be calculated consistently or compared over time.

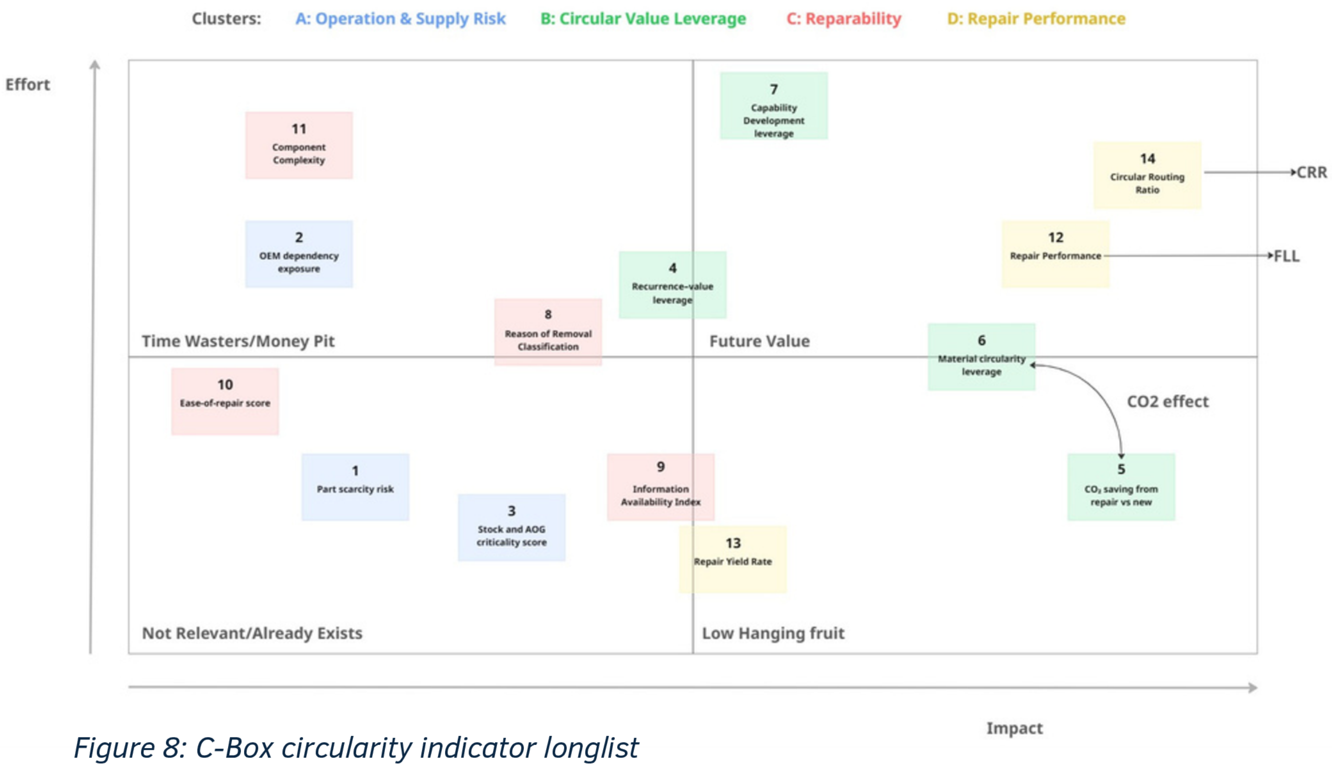


Figure 8: C-Box circularity indicator longlist

6.3 Circularity Blueprint

The indicator workshop also showed that the main issue is not a lack of knowledge about parts or repair, but the lack of a shared way to describe circular value and use it consistently. When circularity concepts were introduced, the discussion repeatedly shifted to process details and terminology. This suggests a sequencing issue: **if the circular logic becomes too complex too early, it creates debate rather than better decisions.**

The Circularity Blueprint addresses that gap. It is a short, practical handout for KLM E&M that creates a shared baseline for circular value retention: what it means in operational terms, why it matters beyond sustainability (value retention and resilience), and what needs to change for it to influence routing and repair capability development. The blueprint is designed for a large, distributed organization where decisions and expertise are spread across many teams. A single reference reduces interpretation drift and supports alignment across levels, especially in a context where routines are stable and change requires clear purpose and relevance for the people doing the work.

Concretely, the blueprint consists of three aspects:

Circular value indicators
set of signals that make value retention and value loss visible in routing, so cases can be compared and discussed consistently.

Circular maturity
clear definition of what circularity looks like at increasing stages, so teams can align on where they are and what needs to improve next.

Stepwise roadmap
high-level order of steps over time, so the organization can move from visibility to steering to governance without turning the plan into a process manual.

The next section starts with the indicator set derived from the workshop. These indicators are the first building block because visibility is the prerequisite for steering: without consistent signals, value loss cannot be compared across parts or used to prioritize which repair capabilities are worth developing.

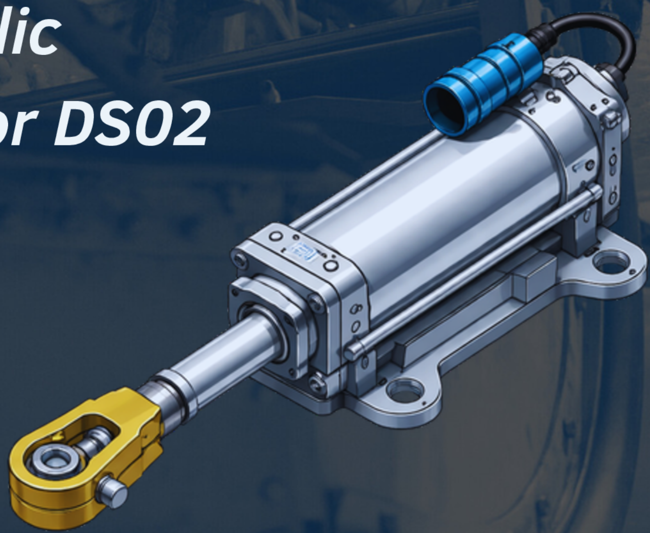
6.4 CIRCULARITY INDICATORS

Currently, costs, recurrence and lead times are the main drivers of deciding on whether to develop a repair capability or not. **To make circular value retention and value loss visible in routing decisions, four circular indicators were created.**

These circularity indicators do not replace the main drivers but are an addition with the goal to make it visible where circularity is lost in a supply chain and part routing. **Making this loss visible is the first step in creating a circular operation.**

For illustration, these indicators are explained using a generic fictitious part:

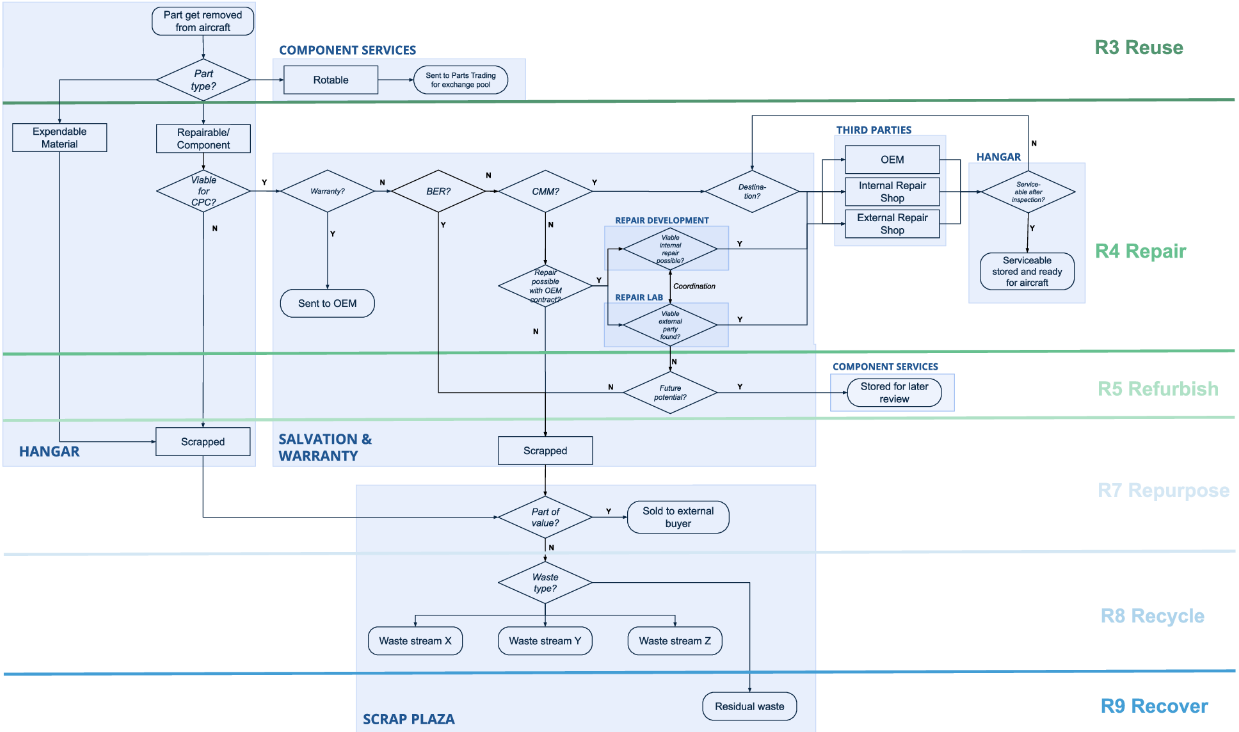
Hydraulic Actuator DS02



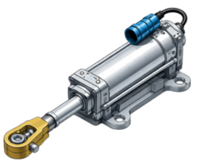
The following pages explain the indicators one by one using examples.

1: R - Level

Records where each routed part ends up in the **value retention hierarchy.** It classifies routes in part routing/supply chain of the operation with a level on the R-ladder framework. This creates a consistent baseline: for each part type it becomes visible what share currently stays in higher loops or moves down to lower loops. **It standardizes the language so routing can be analyzed in circular terms.**

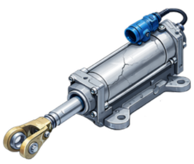


Simplified version of supply chain with corresponding R-Levels for illustration



R3

Re-use by aftermarket of discarded product which is still in good condition and fulfils its original function

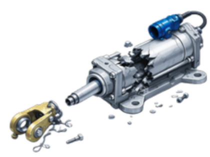


R4

Repair and maintenance of defective product so it can be used with its original function

R5

Refurbish Restore an old product up to date, review stored parts without repair capability for possible development of one



R7

Repurpose Use parts of discarded product in a new product

R8

Recycle Process materials to obtain same or lower grade quality

R9

Recover Incineration of materials for energy recovery

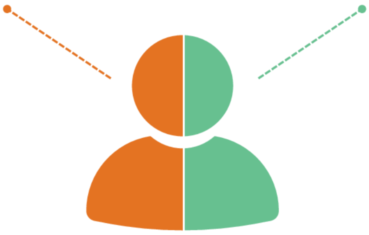
Illustrated examples of R-levels

R- Level Example

Without and with R-level use, how are parts addressed?

Situation

Different teams within a supply chain review in a monthly meeting how the process is going and how it can be improved to retain more value



Without R-Level

"Most of them were repaired or sent to a shop, and the rest was written off or recycled, so I'm not sure what that really means in terms of value."

Outcomes are described in mixed operational terms such as "repaired," "sent to vendor," "written off," "recycled," or "scrapped." **These labels are not consistent across teams and do not map cleanly onto value retention.** As a result, it is hard to see which outcomes kept the part in a high-value loop and which outcomes dropped it into low-value processing. Comparing weeks or comparing part types becomes unreliable because the language shifts with the speaker and the system code.

With R-Level

"Out of this batch, 6 ended in R4–R5 and 14 ended in R8–R9, so most value is still dropping into low-value outcomes."

The same outcomes are translated into a small, fixed set of labels: R4 repair, R5 refurbish, R7 repurpose, R8 recycle, R9 recover. **This makes the routing outcomes directly comparable**: for each part type, it becomes clear what share stays in higher-value loops (R4–R7) and what share ends up in lower-value outcomes (R8–R9). Value loss is visible as a pattern in the routing data, not as an interpretation in a meeting.

R-level tagging standardises routing language so value retention and value loss can be analysed consistently across part types and over time, creating a shared baseline for identifying where improvement efforts should focus.

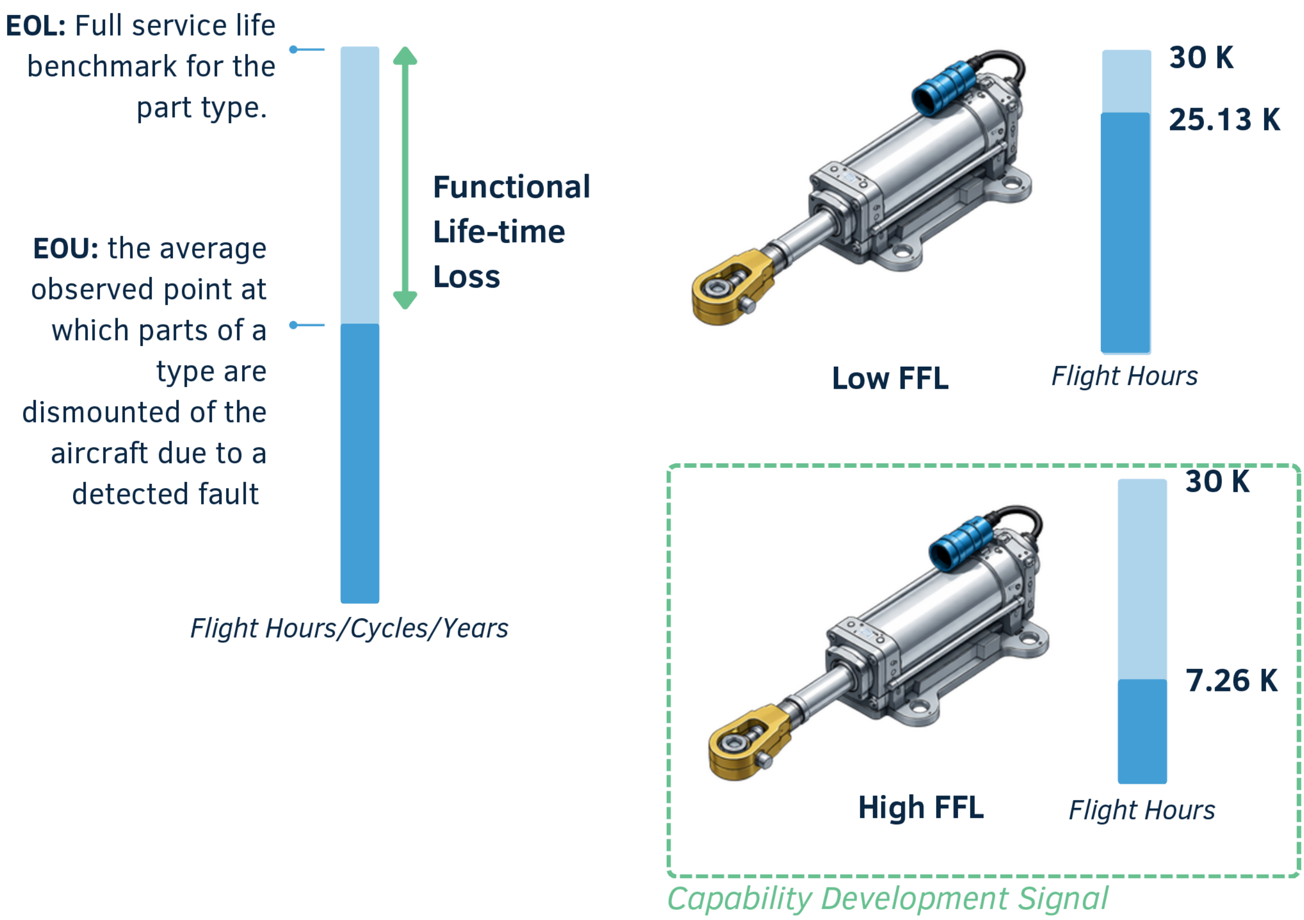
2: Functional Lifetime Loss (FLL)

Derived from the value-retention differentiation made by the UN Environment International Recourse Panel (2018), FLL captures the EOU (end-of-use) and EOL (end-of-life) gap at part level. It quantifies whether part types on average are structurally leaving use "early" relative to their expected service life.

FLL also builds on the logged R-level outcome and is only calculated when the outcome represents an early exit from circulation (for example if a part drops below R4). It compares realised time-in-service at removal to a benchmark lifetime, making "early discard" visible even when routing outcomes alone look acceptable. Using a clear R-level threshold allows for better collecting of the FLL data.

That pattern does not prove that every removed unit is repairable. It shows a loss of X flight hours of potential service life repeatedly in the same part type, which is a **capability development signal.** The follow-up question becomes focused: which failure modes dominate, and can a repair route address them reliably?

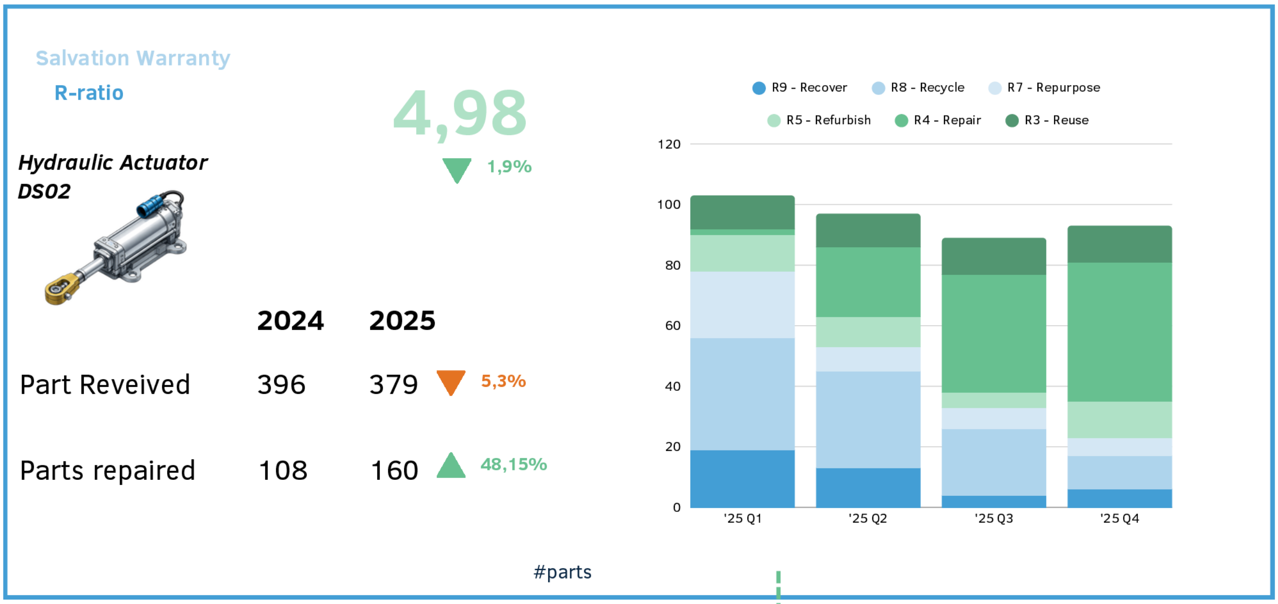
"We are losing approximately 23K flight hours on average for our Hydraulic Actuator DS02. Lets investigate the error that causes this part to get dismounted so early on average. It might be that a specific repair capability fixes that common error, which allows us to get far more flight hours out of the repaired parts"



3: R-Ratio

R-ratio collects value retention for a part type over a period based on the R-outcomes. CRR differs from the R-outcome indicator because **it collects R-outcomes across all routed parts of a given part type over a defined period**, turning single routing choices into a part-type level performance signal.

It expresses how much of the value of repairable inflow is kept in higher-value loops (R3,4,5) versus lost to lower-value loops (R7,8,9). On top of each bar is the average R-ratio of that time period indicated. This tells you the change in performance over time CRR is an outcome indicator that describes the current routing performance for a part type.



Introduction of new repair capability for this part type

Example of CRR tracking

When a repair capability is developed, the ratio can be used to express its realized effect in a single number. The purpose of reducing routing outcomes to one number is to maintain overview for repair development engineers, who monitor many part types. An earlier concept (Appendix J) was rejected because it was too complex to read and an absolute number did not did not show the changes per R level. R-ratio shows both changes per R-level and an absolute number for comparison between parts.

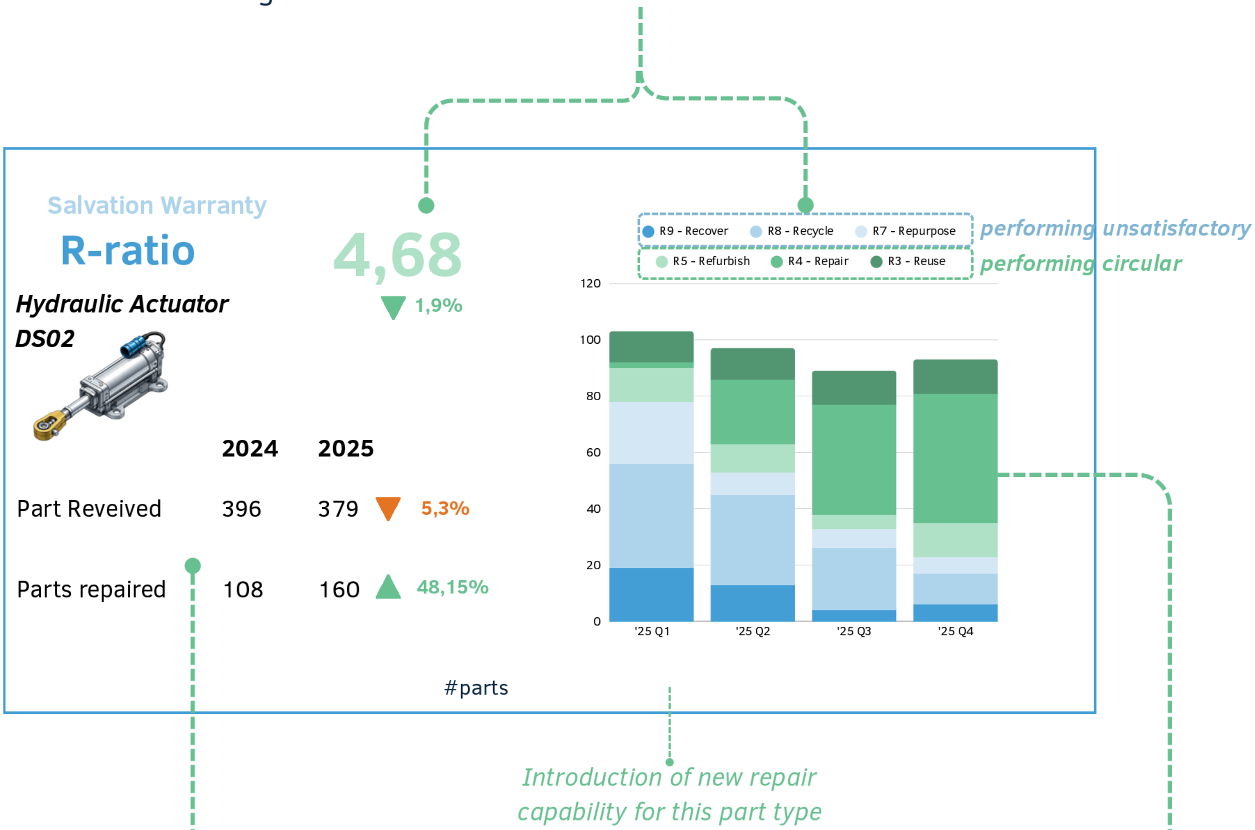
In addition to the absolute number, the change in the rate over time is tracked. This makes it possible to evaluate two aspects of a newly introduced repair capability: **the size of the effect** (does the rate increase, and by how much) and **the speed of adoption** (how quickly the rate shifts after introduction).

E&M can learn from tracking these metrics to use their repair resources better and more effectively in the future to expand their operation and circularity

3: R-Ratio

The total R-ratio shows the latest current R ratio, and how this ratio changed with regards to the previous period, comparable with a stock price indication. This allows for clear overview when comparing a wide range of parts together with one absolute number indicating circular performance

This R-ratio changes to the same color as the R-level to indicate the performance of the R-ratio. A shade of blue indicates that the R-ratio is not performing circular, while a shade of green indicates the average R-ratio is circular



Shows the change in parts received and repaired over the whole year compared to the previous year. This allows to see change over time to track circular performance.

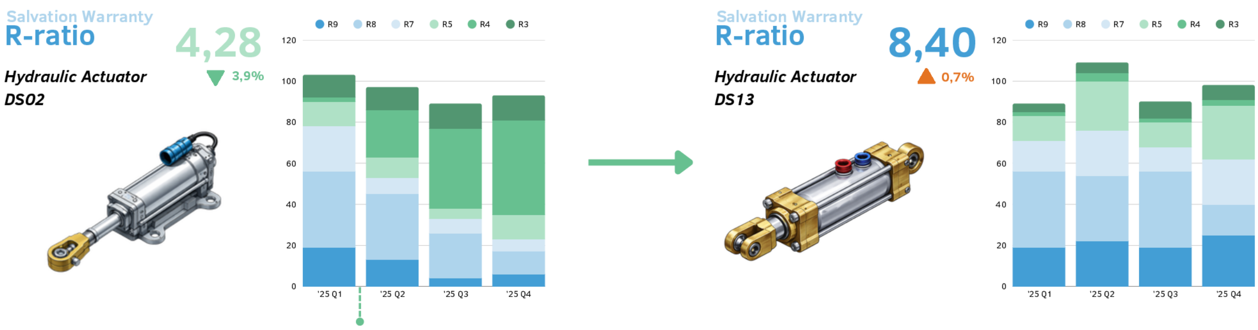
The height of the bars shows the recurrence: this the amount of parts that are observed through a part flow. So how many of this part are dismounted that we need to replace?

Recurrence shows if it is worth to further look into the development of a repair capability. This development costs a lot of time and money, if there are just a few parts recurring, it is not worth to invest in a repair.

The Change in ratio shifting from the 'blues' to 'greens' indicates **more circular value is retained**

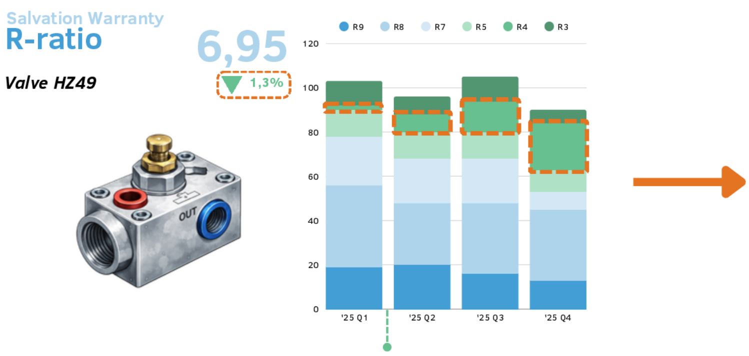
Example Scenario's Circular Retention Rate

"By looking at the increase of the R4 outcomes (middle-green) in comparison to other outcomes quarterly we can conclude: **the ratio shifted toward repair**. The change in the repair rate shows that repair method X works well for the hydraulic actuator DS02, the R-ratio has dropped 3,9% this year. **It may be worth assessing whether the same method can also be applied to a similar hydraulic actuator type** that currently has a high CRR."



Introduction of new repair capability for this part type

"We developed a new repair capability for part Y, however by looking at the slow to no increase in R4 outcomes, **we can conclude there is no significant increase of successful repairs**, the R-ratio should have lowered more by now: **we need to investigate the cause of this inefficiency."**

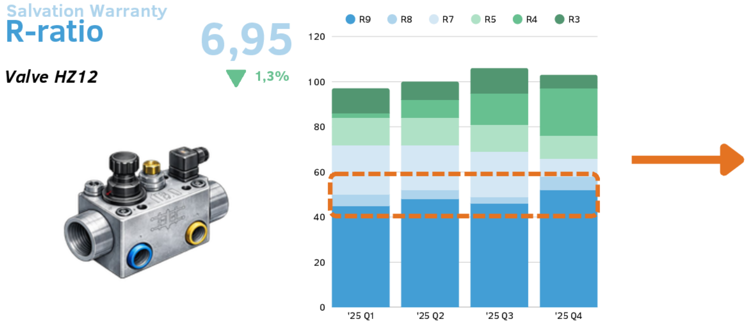


Introduction of new repair capability for this part type

Possible explanation examples:

- ***Incoming condition too poor:*** *parts arrive too damaged for the repair capability to work reliably.*
- ***Learning curve effects:*** *the method works, but mechanics are still trying to learn the capability, early repairs take longer or have higher failure rates*
- ***Wrong failure mode:*** *the new method fixes only one failure mode, but most incoming parts fail for different reasons.*

"By looking at the small to none existing R8-recycle outcome layer (middle-blue), we can conclude that our operation can hardly recycle this part and ends up mostly in R9 (dark-blue). **This is a circular indicator** to repair/refurbish the part to **prevent large circular value loss**"



- *The part consists of too many different materials to successfully recycle*
- *Mechanics have no clear indication of where/how to discard the part after dismounting it of an aircraft*

4: Indicative CO_2 Effect

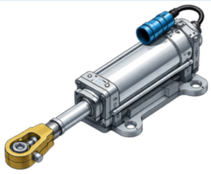
The indicative CO_2 effect estimates the emissions associated with a part type by comparing two routes: **producing a new part versus extending its life through repair**. The underlying values are not created in this thesis, they build on a rough per-part calculation that was previously produced by an external party and captured in an internal confidential Carbon Assessment Report. However, **this information is not yet used structurally in routing decisions, which makes it a practical low-effort starting point**. The indicator is therefore used as a directional comparison, not as a full LCA, and helps distinguish where circular value retention is likely to deliver materially different climate effects across part types.

Using an indicative CO_2 effect helps E&M reduce transition risk by making the emissions impact of repair-versus-replace decisions visible early. As the shift to a climate-neutral economy accelerates through new regulation, technology changes and market expectations, the relevance of Scope 3 action and reporting is likely to increase, and having a consistent decision-level signal helps E&M stay ahead rather than react late (TNO, 2024). If E&M reacts late, the practical consequence is a **catch-up mode:** ad-hoc data collection and inconsistent assumptions under time pressure, delayed prioritisation of repair development, and contested narratives about whether decisions meaningfully reduce emissions, this while Scope 3 measures can start to affect competitiveness, costs and supplier/customer expectations

The CO_2 effect builds on the logged R-level outcome: the R-level determines which route occurred (retain route versus replacement route), and a simple factor set is applied to estimate the avoided or incurred impact. This structure can be extended in the future by assigning indicative CO_2 factors to each R-level, so every routed outcome carries a comparable directional impact signal.

In practice, it makes visible that repairing larger, metal-dominant parts typically avoids more embodied emissions than repairing small, lightweight plastic parts for example, even when prices or volumes are similar. The indicator is therefore taken into account alongside price, recurrence, and lead time when selecting part types for repair capability development, and it aligns this prioritisation logic with KLM's long-term Climate Action Plan.

"Lets prioritize developing a repair capability for the Hydraulic Actuator DS02 instead of the Rail Clamp. This way the repair capability has far more impact reaching our set CO2 reduction target"



Purchasing Document	235632
Description	Hydraulic Actuator DS02
Supplier Name	Actuate International
Country	US
Used/New	Repair
Purchasing Group	242
Net Order Value	$32.400,00
Department	Airframe
Material Group	002
Purchase/Repair	Repair Order
Emission Factor	330.142 kgC02/k$
Emission Factor Type	Aluminum-based manufactured parts
Emissions	**25,52 Kg C02**

Purchasing Document	735764
Description	Rail Clamp HE0423
Supplier Name	E.M. Plastics
Country	DE
Used/New	Repair
Purchasing Group	142
Net Order Value	$35,00
Department	Airframe
Material Group	062
Purchase/Repair	Repair Order
Emission Factor	1.142 kgC02/k$
Emission Factor Type	Plastic-based manufactured parts
Emissions	**0,047 Kg C02**

figure 9: Part information Carbon Assessment Report for illustration

6.5 DESIGN REQUIREMENTS CHECK OF THE INDICATORS

The indicators were not designed as separate solutions, but as one linked system that builds from a shared outcome language. This matters because the design requirements also form a chain: circularity only becomes workable when outcomes are comparable, logged, steerable over time, and expressible in the same trade-offs that already govern routing decisions. The section below revisits the design requirements and communicates how the indicator system meets them through interaction.

1 Objective: The redesigned decision logic must **treat parts as assets retained in circulation by default**, increasing the share of higher R-level outcomes wherever technically and contractually feasible and financially viable. Specifying reasons for lower R-level outcomes.
*The system forces an explicit "asset outcome" per routed part by logging an **R-level label** at the routing moment, then registers all for that part type. That does two concrete things: **it makes "retain-by-default" measurable** (share of repair/reuse/refurbishment outcomes) and **it makes exceptions explicit** (which low R-level outcomes keep happening for which part types). The trend view (R-ratio over time) is what turns the philosophy into steering: it shows whether a part type is drifting toward replace/scrap or improving toward higher loops.*

2 Steering Trigger: The decision logic must include **clear signals and triggers that highlight structural value loss** and link these cases to available mechanisms for developing or sourcing alternative repair options.
*Triggers come from **repeating patterns**, not individual cases. Using the logged R-levels, the system flags part types with **persistent low-loop outcomes** (e.g., recurring scrap, repeated new-buy). Those patterns can be tied to simple thresholds (low R-ratio for a period; scrap frequency above a set level) and then routed into the existing mechanisms: **repair development, alternative sourcing, or partner capacity.** FLL helps to choose where to start by showing where early discard is highest.*

3 Governance & Traceability: Decision-making must be structured so that **routing outcomes are logged, traceable over time and clearly owned**, enabling systematic identification and follow-up of opportunities to keep parts in higher-value loops.
***One thing is logged at the routing moment: the part's R-level outcome.** Everything else uses that same record: R-ratio is the trend of those R-levels, FLL is added when the R-level shows an early exit (scrap/replace) by comparing time-in-service to a benchmark, and the CO_2 effect is added by applying a factor linked to the R-level (retain vs replace, later per R-level). Because all signals sit on one record, ownership is clear and follow-up can be reviewed against the same dataset.*

4 Boundary Condition: Circular value must be integrated alongside existing constraints of safety, airworthiness, contractual terms and availability, so that routing decisions remain compliant and operationally robust while making better use of repair and reuse potential.
***The indicators do not change gate rules; they make the results visible.** If warranty/exclusive authority forces an OEM route, that stays, but it becomes measurable as a repeated pattern. Effort then goes to the parts where agency exists: approved repair routes, partner options, internal capability, and information timing—and improvement shows up as changed outcome trends.*

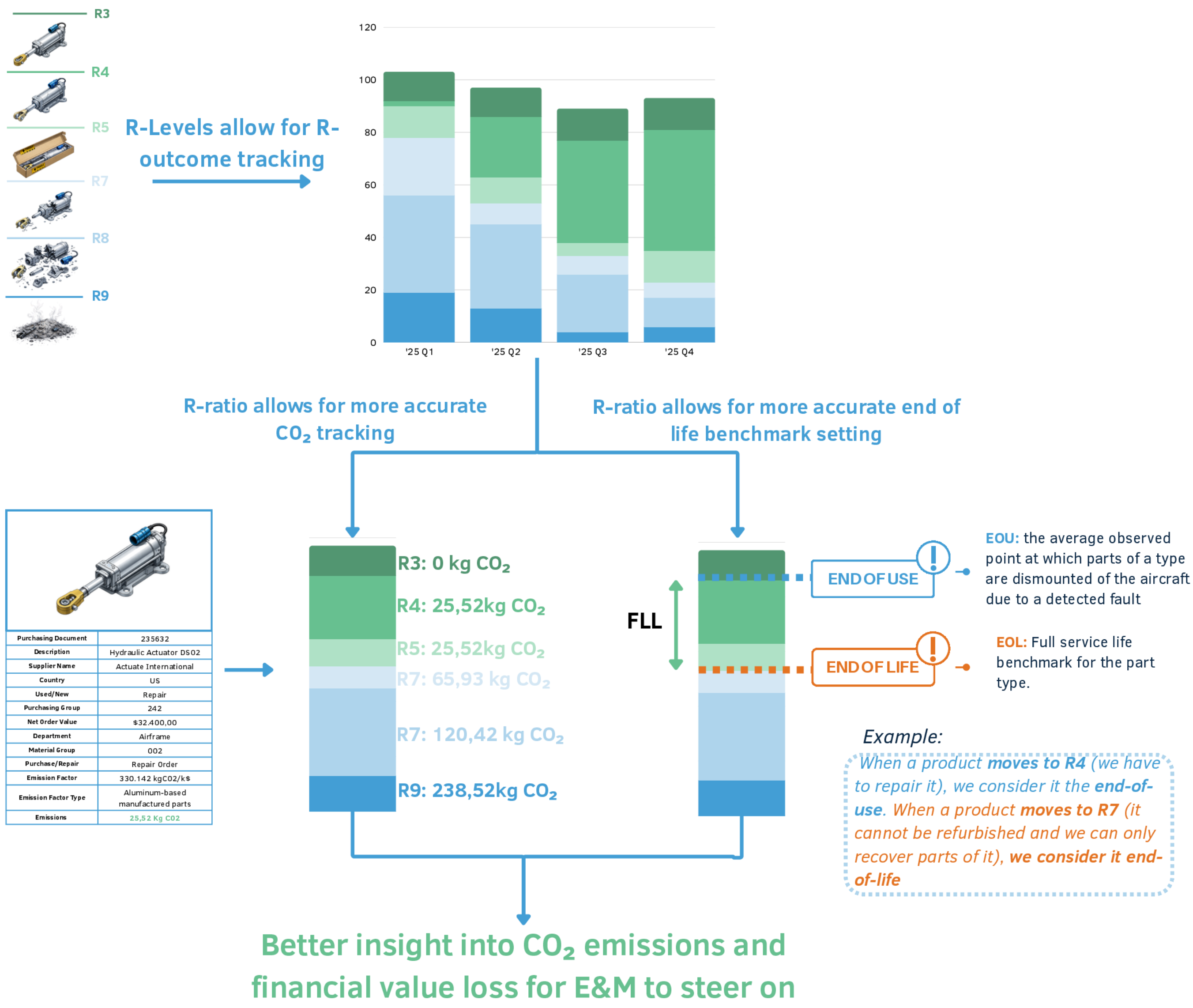
5 Value Accounting: The process must make the financial and environmental effects of routing choices visible in a simple way, so that the retaining **circular value can be weighed explicitly** against other performance measures.

The system adds one "impact layer" on top of the same outcome record. *Today, the indicative CO_2 effect can compare repair vs replace in a simple way. Later, the same logic can assign CO_2 factors to each R-level once logging is stable. Financially, FLL (lost hours/cycles vs a benchmark) can be translated into lost € value by linking that shortfall to part price and replacement logic,* ***so early discard is weighable next to cost, lead time, and risk.***

Why keep all four indicators and not proceed with a single 'best' concept?

No single indicator satisfies the full chain of requirements without becoming either too vague to steer or too complex to adopt. The system works because the layers depend on each other: the shared outcome language makes logging possible, the trend layer turns logs into triggers, the performance layer prevents false comfort, and the impact layer makes circularity discussable in approval logic. Removing one layer breaks that chain, which is why the thesis proceeds with the system as a whole rather than selecting a "best" indicator.

COMPLEMENTARY DYNAMICS OF THE INDICATORS



Why reduce rich circular information to just two headline numbers: CO_2 emissions and financial value loss?

This indicator set only creates impact if it ultimately lands in a form that decision-makers can weigh in resource allocation. This became clear in a meeting with higher-level E&M stakeholders (department head level) who are responsible for assigning man-hours and budgets.

After a detailed explanation of the indicators, they asked a simple question: *what is in it for us, why would we do this?* A fair question. It showed that, **to be workable beyond the operational level, indicator outputs must translate back into the numbers managers already steer on.** Only then can circular value be compared to other priorities and can additional resources be justified.

This insight shaped the final indicator logic. The indicators are complementary, but the direction is convergent: together they translate circular value into two steerable outcomes for E&M: financial value loss for resource steering and CO_2 emissions for sustainability steering.

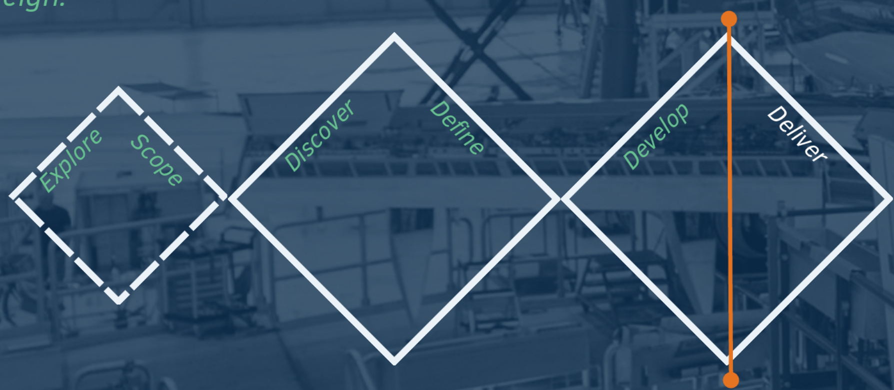
The meeting in question, with me presenting the indicators to the stakeholders (sitting at a wingflap)

VII
Implementation Plan

Making the indicator set implementable for E&M

TAKE AWAYS FROM DEVELOP

1. *Indicators must fit real decision moments and existing routines.*
2. *Use depends on clear ownership, low effort, and credible definitions.*
3. *Adoption needs implementation over time to avoid pushback and overload.*
4. *Indicators complement each other leading to better insight into emissions and financial value loss*
5. *This indicator set only works if it eventually lands in a form that decision makers can actually weigh.*



GOAL

Translate the developed indicator concepts into an implementation plan that can be executed in the operation.

FOCUS

1. What actions are needed to move from concept to daily use?
2. Who owns what (responsibilities, handovers, governance)?
3. What are the success criteria and how will they be checked?
4. What is the reasoning for this sequence and these roles?

METHODOLOGY

1. Design Roadmapping
2. Visualization of horizons
3. Validation of concept
4. Creating an interactive workable deliverable for E&M

7.1 MAKING THE INDICATOR SET WORKABLE FOR E&M

The previous phase defined the indicator set and clarified where circular value is gained or lost in routing. ***Deliver focuses on a different challenge: adoption.*** *The output must survive day-to-day operations. That requires clear ownership, a fixed review rhythm, and a format that travels across teams without constant explanation. It will focus on implementation logic: an interactive Circular Blueprint and a staged roadmap that turns the concept into routine use.*

Why a roadmap?
An indicator set only matters if it changes how decisions are made. Different teams encounter the same case at different moments and with different information and urgency. For example, S&W sees the serviceability tag and warranty constraints at intake, Repair Development evaluates repair potential under lead-time and cost pressure, and the Repair Lab faces the practical feasibility in execution (manuals, missing pieces, tooling), often only after earlier routing choices have already narrowed the options. In that setting, circularity fails in predictable ways: inconsistent language, missing logging and discussions that drift into exceptions, as observed in the indicator workshop.

A roadmap is defined as: a visual portray of design innovation elements plotted on a timeline. Road maps not only provide strong visualisation and decision making support – they foremost enable organisations and designers to devise creative responses to future strategic challenges and create a tactical plan to turn vision into reality (Simonse, 2017). That is exactly the function in this context: **stage circularity in horizons so it becomes workable.** The horizons in the roadmap are an adoption control mechanism. They separate what can be implemented now from what requires maturity in data, routines and governance. The strategic roadmap gives the clear overview, while the tactical roadmap elaborates and justifies it as a reference with the underlying actions, ownership logic and rationale. It also converts visibility into steering by specifying when indicators enter routines, who owns them, and how follow-up becomes non-optional.

The time windows were set with the Tech Hub program lead by comparing with the lead times of similar changes in E&M. **The point is realism: enough time for routines to settle, not too long for the plan to disappear in the background.**

Each horizon has one dominant job.
Horizon 1 creates a shared outcome language and a baseline view.
Horizon 2 stabilizes logging and turns visibility into steering.
Horizon 3 embeds circularity into normal governance and scales into the external ecosystem.
This order follows a simple dependency: **steering only works after consistent logging, advanced signals (FLL and R-ratio feedback) only work after the foundation is stable.**

Back & forecasting

The indicator set was developed first as a concrete way to embed circularity into repair capability development decisions. From that target state, backcasting was used to define what actions and prerequisites are needed to move from today's situation to consistent use of those indicators in practice. Backcasting is a strategic problem-solving framework for answering the question on how to reach a desired future state by linking goals and sets of steps to achieve that (Bibri, 2018).

After reaching this goal and the indicators can be used reliably, the focus shifts to forecasting their organizational potential. The question becomes how the indicators can scale across E&M? What needs to scale with them? And what new advantages does that create for the organization and the people doing the work? Interviews, mainly with the sustainability lead, reinforced that this scaling step depends on communicating the value in operational terms, because initiatives only persist when stakeholders understand what it improves for them and how it strengthens the operation.

HORIZON 1		HORIZON 2		HORIZON 3
BACKCASTING	←	**INDICATOR SET**	→	**FORECASTING**
What actions need to be taken to get there?		*What would Circularity look like in E&M MRO operation?*		*What potential does circularity have for E&M when scaled?*

Circular Blueprint as an interactive website

The Blueprint is designed to be shared, revisited and used in meetings: it needs to be a workable deliverable for E&M. The website format is chosen to support steering: **it keeps definitions and usage instructions close to the recurring decision moments where the indicators must be applied and is easier to distribute among all stakeholders and harder to "lose" in a drawer.** It also lets different audiences enter at different depths: management can scan the roadmap and targets, engineers can jump directly to definitions of R-levels and usage instructions of the R-ratio for example.

This choice was tested for feedback. An E&M management trainee (Strategic Design graduate) confirmed that the result communicates clearly and feels desirable as a practical artefact, not as a "thesis product", slight adjustments to better fit company jargon were made. The website has already been circulated in a six-month Cabin of the Future (CIRCADIS) update to a group of roughly 40 internal stakeholders and another TU Delft graduate will follow up on working out the indicators. **This is an initial interest signal of how the blueprint can gain traction in the organisation.**

A circular operation is a more sustainable operation. The Circular Blueprint allows all levels in the organisation to visibly and objectively contribute to CO_2 reduction and to KLM's Climate Action Plan, making progress on sustainability more than just a management target.

7.2 EVALUATION APPROACH: DESIRABILITY, FEASIBILITY, VIABILITY

The Circularity Blueprint will be evaluated along three criteria: desirability, feasibility and viability. Desirability assesses whether the deliverables address stakeholder needs and decision values in the MRO routing context. Feasibility assesses whether the deliverables can be executed under operational constraints, including distributed ownership, and data availability. Viability assesses whether the deliverables can persist over time through governance, ownership, routines and integration into existing decision cycles.

Evidence for the evaluation is drawn from three sources: (1) **iterative expert interviews** and follow-ups used to reconstruct decision gates and constraints, (2) **the indicator focus workshop** where indicator concepts and adoption frictions were stress-tested, and (3) **targeted feedback** on the Blueprint format and roadmap logic to verify clarity and perceived workability for E&M stakeholders. The evaluation therefore combines demonstrated alignment with operational reality (feasibility), observed stakeholder acceptance signals (desirability), and a governance-based implementation logic (viability) expressed through the staged horizon roadmap.

The three-horizon structure is treated as an adoption control mechanism: Horizon 1 establishes shared outcome language and baseline visibility; Horizon 2 stabilizes logging and turns visibility into steering; Horizon 3 embeds circularity into governance and scales into an external repair ecosystem. This ordering follows a dependency logic: **steering requires consistent logging, and advanced signals require stable assumptions to avoid data debates.**

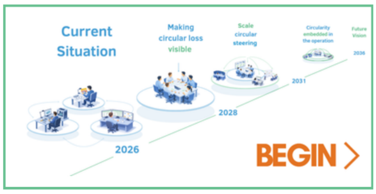
7.3 EVIDENCE AND RATIONALE OF BLUEPRINT NAVIGATION

To avoid duplicating content in the main text, the Circular Blueprint is documented in Appendix Z and in the accompanying interactive website. The following chapter provides additional context and substantiates each Blueprint element with supporting rationale and evidence on desirability, feasibility, and viability. This structure keeps the thesis readable while allowing the Blueprint to be reviewed in the format in which it is intended to be used.

https://qrco.de/CircularBluePrint

DESIGN ASPECTS

Every blueprint aspect has a reasoning and design choice behind it, appendix X shows a 1pager showing the origins of each illustrative element.



Landing page, section 2

repair development meeting as the illustrative backbone

The Blueprint uses a recurring repair development meeting as the storyline because that is where leverage sits. This is the point where repeated failures, feasibility constraints, OEM dependence, cost pressure, and capacity constraints collide. It is also where "learning" can be converted into capability decisions.

Using the same meeting across horizons makes the maturity shift visible. In Horizon 1 the meeting gains shared language and logging discipline. In Horizon 2 it gains trend steering and a standard decision template. In Horizon 3 it gains lifecycle signals and ecosystem governance, so choices persist beyond individual champions. Appendix Y shows the iterative design process of the evolving meeting.

H0: PRESENT

H2: STEERING

H1: VISUALIZING

H3: EMBEDDING

Ecosystem as part of the deliverable

If the circularity indicators already prevent value loss, why does E&M need an ecosystem too?
When the circular indicators show value loss and make better cases for repair capability development, this means more repairs and so expanding the repair capabilities. Circularity at scale is constrained by capacity and specialist labor. Internal capability will not cover all demand swings. The roadmap therefore treats the external repair ecosystem as a structural element, not an add-on.

This was grounded in interview evidence. A repair developer described cases where external parties such as Egmond Plastics and Belgraver for example, recreate plastic parts as a cost-saving alternative to OEM sourcing, but also noted that such partnerships are still limited because relationships take effort to build.

The same logic supports FLL: its core value is not only internal steering but feedback to suppliers. E&M holds rich performance data. OEM suppliers often lack visibility after delivery. **A mature horizon can convert E&M data into upstream learning: clearer performance feedback, better repair instructions, and more targeted agreements.**

To visualize this initial standardization in meetings from H0 to H1, and the growing ecosystem in H1-H3, increasing concentric circles where used to show this progression, as seen in figure 10.

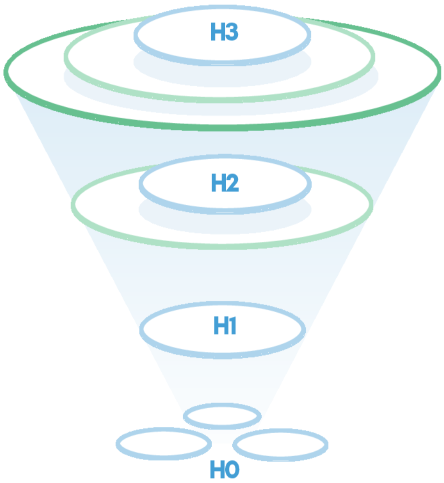


Figure 10: Ecosystem visualization

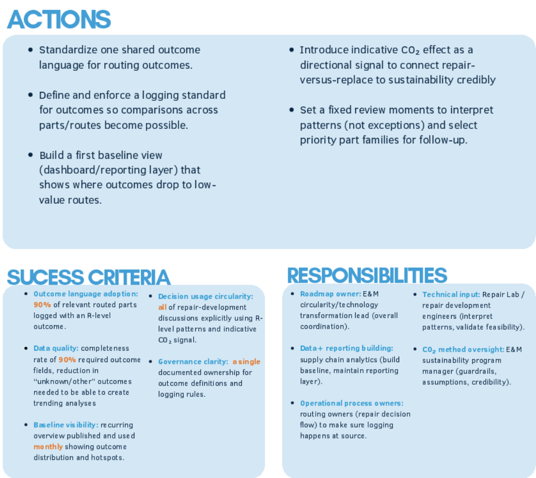


Figure 11: Action, criteria & responsibility division for each horizon

Action placement and criteria quantification

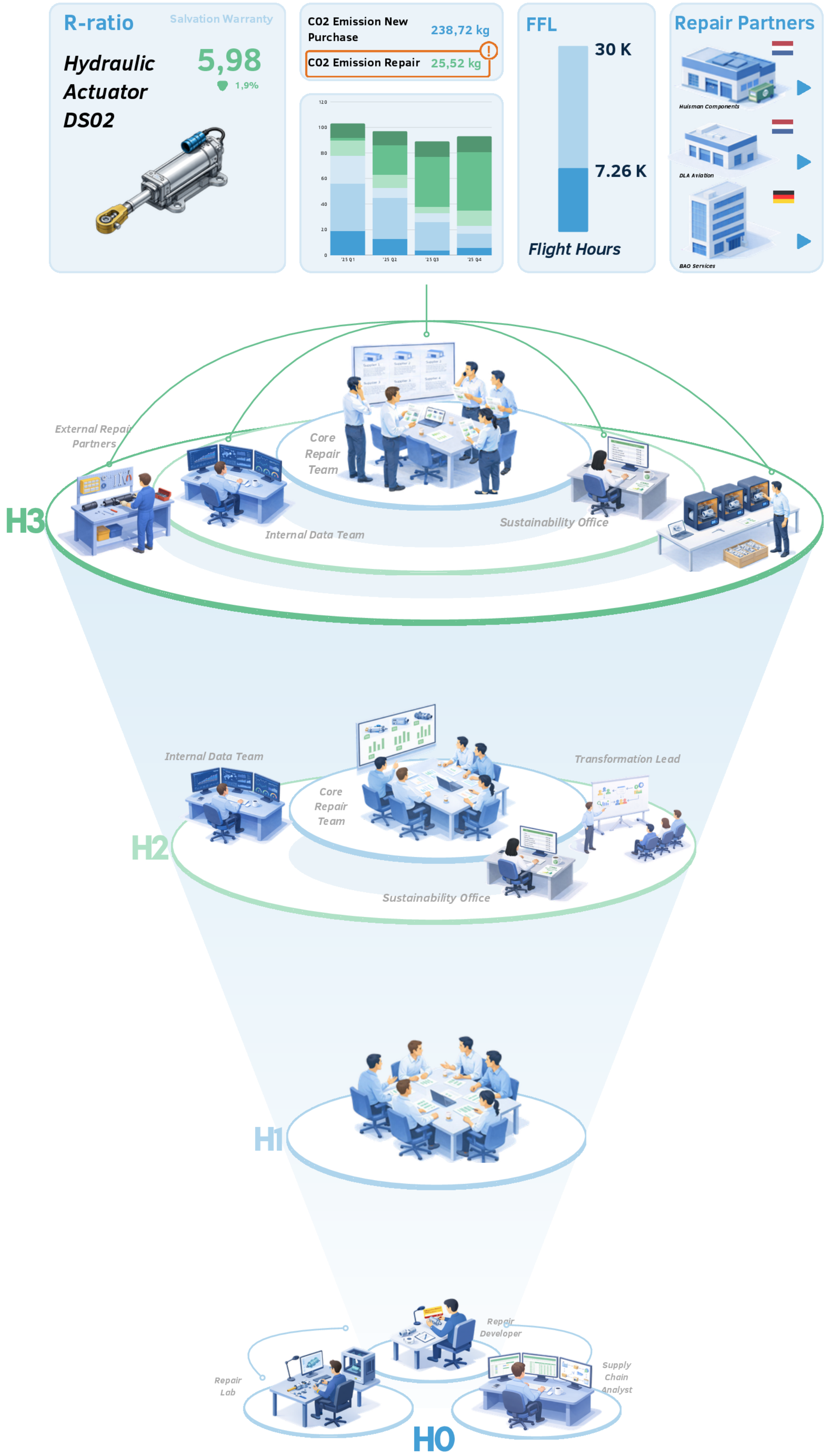
E&M runs on routines and ownership. **If a change is not tied to a role and a metric of success it degrades into optional behavior.** That is why actions are placed first: they answer the operational questions immediately. *Who owns this. When is it reviewed and when is it a success?*

Quantification is part of the same logic. It removes interpretation work. It prevents the discussion from becoming "we think it improved." It also makes it easier for team leads to hold responsibility in a hierarchical structure such as E&M.

This quantification was made in collaboration with the Tech Hub program lead (appendix M). Success criteria were made concrete by tying them to realistic review moments, such as monthly visibility updates for baseline steering. Targets for improvement were calibrated to what is seen as achievable (for example, quarterly reduction ranges for repeated low-value outcomes in selected part families).

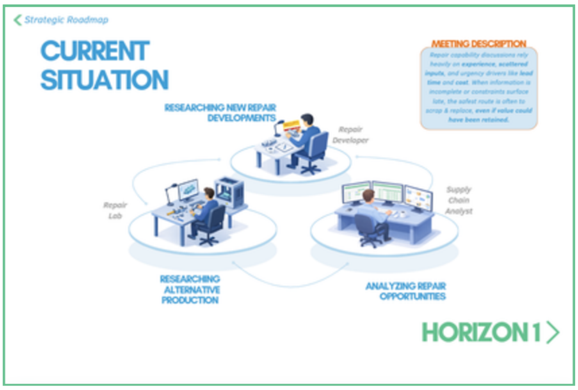
7.4 THE EVOLVING REPAIR CAPABILITY MEETING

The following chapter dives deeper in the evolving meeting per horizon, explaining reasoning and evidence.



CURRENT SITUATION

The current situation can be characterized as a largely linear decision logic in which **routing and repair capability development are optimized for safety, operational continuity, and direct cost.** In practice, repair is pursued where it is clearly feasible and justified, but circular value is not used as a consistent steering dimension, and potentially recoverable value can be lost when information is incomplete and the safest default becomes replacement or scrap.



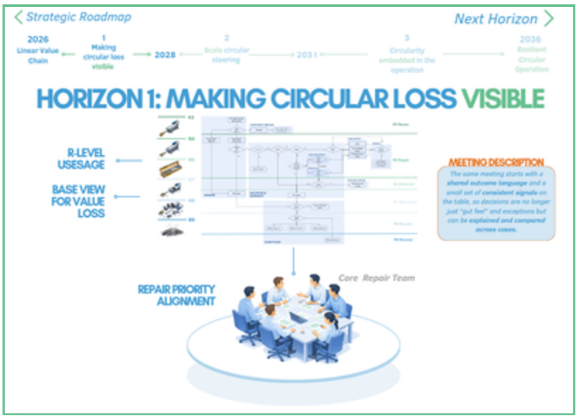
Current situation page

This conclusion is based on interviews with core stakeholders involved in repair capability development and routing decisions, including supply chain analysts, repair development, and Repair Lab roles. Across these perspectives, the same decision drivers repeatedly surfaced: new-buy price, lead time and availability risk, recurrence, and capacity constraints. **Circularity was typically acknowledged as relevant, but it was not described as something that is operationalized in shared language, routine decision templates, or performance steering.**

This means that implementation cannot start with complex circularity metrics or detailed optimization (as seen in the circularity indicator workshop). The first requirement is to **create a shared, workable way to recognize circular value in the existing decision context,** so that cases can be compared consistently and the organization can shift from ad hoc judgment to deliberate steering over time.

HORIZON 1

Horizon 1 is the point where circularity becomes **visible** in E&M, because value loss stops being implicit through the introduction of the R-levels. As a first step, the R-levels can be used to review part routings and supply chains similar to the S&W case to identify where value loss occurs. Interviews and the indicator session showed that the organisation does not lack expertise about parts, constraints, or repair; the gap is that outcomes are not described in a consistent way across roles and decision points. As a result, cases cannot be compared and discussions keep falling back to local exceptions.



Horizon 1, including action, sucess criteria and responsibilities

The workshop also showed that starting with detailed circular metrics triggers definition and data debates instead of action. Horizon 1 therefore focuses on shared outcome language and minimum logging so routing results become comparable without changing the operational priorities of safety, continuity, and cost.

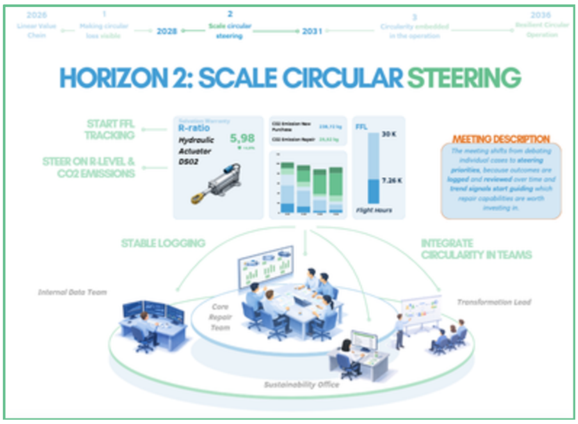
The main obstacle to overcome in this horizon is to **treat shared outcome language and logging as necessities for implementation, not as additional administrative overhead.** Without broad adoption, a dashboard has no steering value and a meeting will revert to gut feel and old habits because the data is incomplete. This is why the success threshold is framed around coverage and completeness of at least **90%**. If outcomes remain unknown in a large share of cases, any trend view becomes unreliable and will be dismissed by practitioners. A baseline view is introduced not to optimize, but to make recurring loss patterns visible enough to support prioritization. **The goal is to move discussions from one-off cases to patterns that recur across part families**, because that is the only level at which repair capability development can be managed deliberately.

At this stage, the indicative CO_2 signal is **a consistent directional comparison that connects repair versus replace to sustainability without claiming precision**. This matches the maturity level identified: CO_2 can support reasoning and future readiness, **but it should not be positioned as a decisive metric until governance and data discipline are in place.** Finally, fixed review moments are necessary because visibility alone does not change behavior. A recurring rhythm forces interpretation of patterns, makes it possible to select priorities, and establishes accountability for follow-up, which directly addresses the governance gap that surfaced in stakeholder input.

This horizon is two years because it builds on what already exists: the decision moments and operational knowledge are in place, and the first step is primarily standardization and discipline. The limiting factor is not technical feasibility but adoption and coverage, which can be achieved quickly if the logging burden stays minimal and ownership is clear. Shorter than two years is unrealistic due to the scale of the E&M operation.

HORIZON 2

Horizon 2 is the point where circularity moves from visibility to steering. In Horizon 1, R-levels make value retention and loss explicit; in **Horizon 2, those outcomes are used to guide repair development effort over time.** The evidence for this step is consistent across interviews and the indicator session: the organisation does not lack technical knowledge about parts, constraints, or repair options. The gap is that outcomes are not yet comparable and consistently followed up, so improvement depends on isolated cases rather than a repeatable learning loop.



Horizon 2, including action, sucess criteria and responsibilities

Steering becomes possible once outcome logging is stable and a recurring routine uses trends to allocate effort. Without that, it remains unclear whether repair development reduces repeated low-value outcomes or only delivers occasional successes. Horizon 2 therefore shifts the unit of attention from individual cases to patterns across cycles: **which part families repeatedly drop to low-retention outcomes, where those drops occur, and which issues justify deliberate capability investment.**

The focus in this horizon is procedural rather than technical. **It standardises how repair capability proposals are built and reviewed so cases can be compared on the same evidence, trade-offs become explicit, and decisions rely less on personal narrative.** In line with supply chain decision theory, performance improves through stable information structures and feedback loops that connect decisions to outcomes, not through adding more complex metrics in isolation (Sterman, 2015).

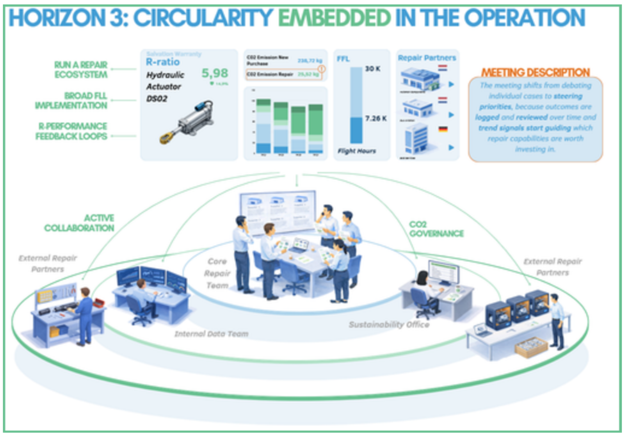
In practice, **R-ratio** becomes the main steering signal, used in a fixed pattern with assigned follow-up actions. Functional Lifetime Loss (FLL) becomes feasible as a selective indicator for part families where flight-hour data is available and benchmarks for total lifetime can be defined. This indicator improves repair development decisions by showing when early discard or replacement leads to avoidable loss of functional.

It also starts building ecosystem resilience: not by claiming independence from OEMs, but by defining when and why alternative repair routes are worth pursuing within certification and OEM limits. **The end state of this horizon is a way of steering repair capabilities that can show improvement, explain trade-offs, and learn from results.**

This horizon takes roughly three years because steering requires multiple stable cycles: enough time to build comparable data, implement targeted interventions, and show that actions shift outcomes, not just dashboards.

HORIZON 3

In Horizon 3, **circular value retention is no longer sustained by a project effort but by how E&M routinely manages performance**. The meeting is no longer about proving individual repair cases. It becomes a steering moment where the same indicator signals are treated as standard decision inputs and where outcomes are used to update thresholds, rules, and capability focus.



Horizon 3, including action, sucess criteria and responsibilities

This shift is justified by the earlier findings: once visibility and trend stability exist, the limiting factor stops being "insight" and becomes "capacity and option space." Interviews already pointed to two structural pressures that cannot be solved with dashboards alone, namely specialist labor scarcity and dependency risk from OEM pricing, lead times, and restrictions. **Horizon 3 therefore focuses on scaling viable repair routes while keeping compliance.**

The core of this horizon is a managed repair ecosystem. E&M deliberately coordinates a hybrid model that combines in-house capability with certified partners, selected for specialization and capacity. This reduces exposure to OEM power and supply shocks where alternatives exist, and it prevents internal staffing constraints from becoming the bottleneck that forces value loss back into the system.

At the same time, governance maturity on CO_2 effect steering moves from a directional signal to a decision-relevant signal because the method and assumptions are owned, versioned, and auditable. Functional Lifetime Loss is expanded for part families where flight-hour or cycle linkage and benchmarks are reliable and where the signal changes repair versus replace decisions. **The feedback loop becomes explicit and continuous:** outcomes are reviewed, guidance is updated, and capability strategy is adjusted based on observed results rather than anecdotal success.

These success criteria reflect whether this has become an operating model rather than an initiative. The ecosystem should absorb demand swings so capacity is not the limiting factor for priority repair decisions. Reliance on OEM purchases should reduce where compliant alternatives exist. CO_2 and lifetime signals should appear in documented trade-offs as a normal part of repair development decisions, not as optional add-ons. **Value retention outcomes should therefore show continued improvement at system level**, for example a 5 to 7 percentage point improvement in the relevant R-ratio signal over time for the targeted scope. Most importantly, **indicator use should persist through normal ownership and routines**, meaning the transformation lead can step back without the practice collapsing.

Responsibilities follow the same logic. **E&M acts as ecosystem coordinator, setting network strategy and resilience targets.** Supply chain and procurement manage partner pathways through contracts, capability mapping, and performance oversight. Repair domain leads own in-house capability strategy and technical standards. Indicator governance sits with the operational stakeholders as embedded ownership, with sustainability governance ensuring CO_2 methodology remains auditable and aligned with external reporting expectations.

Horizon 3 addresses the OEM–MRO power shift. When OEMs control data and repair approvals, the bottleneck is not "can we repair it," but "do we have an approved route we are allowed to use." Circularity at scale therefore depends on increasing the number of compliant repair routes.

In this horizon, E&M builds a managed repair ecosystem: secure access where the OEM controls it, lock in qualified repair partners and develop additional approved routes where possible.

This horizon takes five years because it involves structural capability change: building and governing a hybrid repair ecosystem, reducing OEM dependence where alternatives exist, and making CO_2 and lifetime signals decision-grade and auditable. These transition requires contract cycles, certification pathways, organizational change and sustained feedback loops before they become the default way of working.

7.5 STRATEGIC ROADMAP

Current Situation
Linear value chain

2026 — 1 Making circular loss visible — 2028 — 2 Scale circular steering — 2031 — 3 Circularity embedded in the operation — 2036

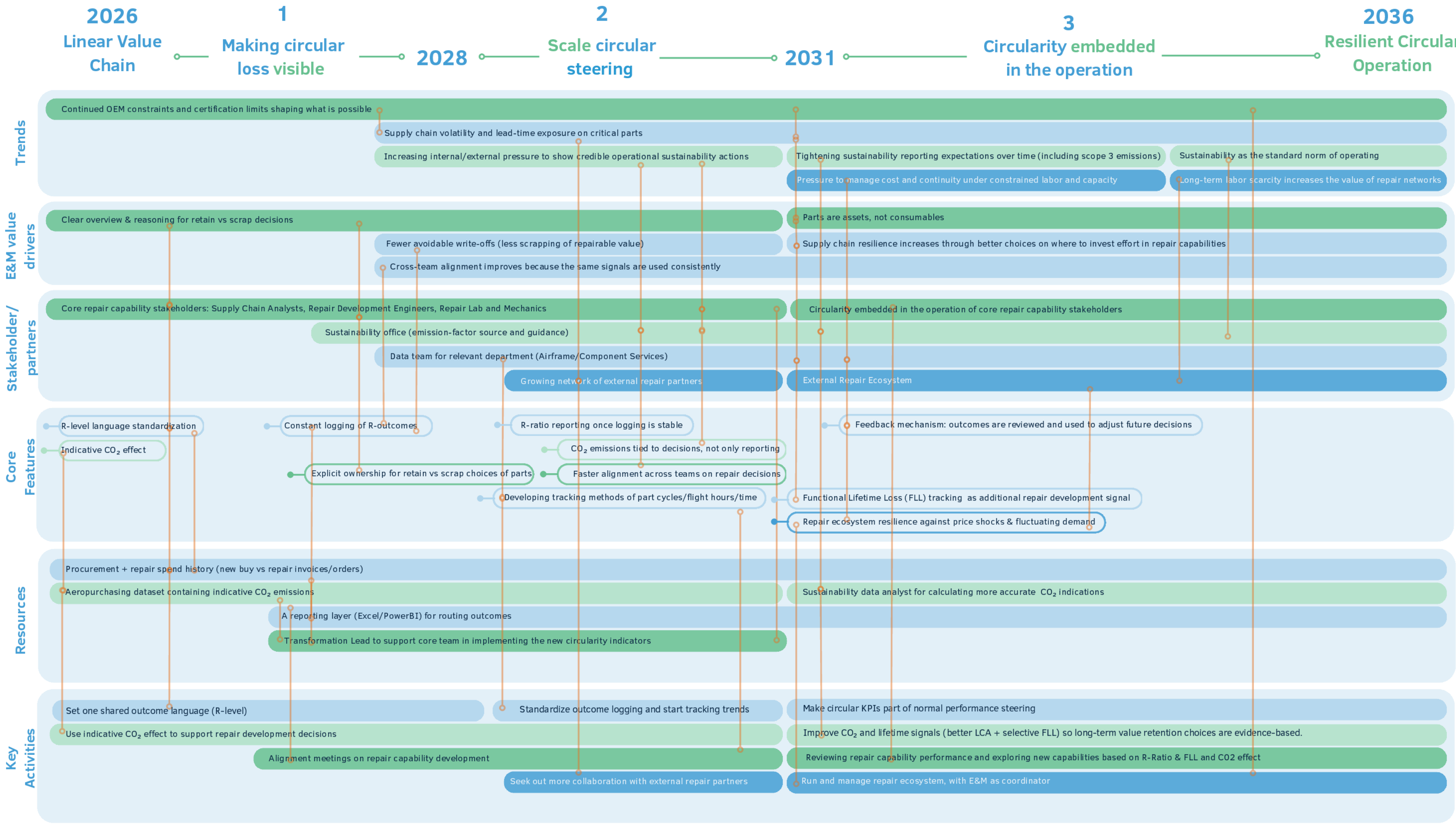
Future Vision
Using circularity to run a resilient MRO operation

	1	2	3
Drivers	• Circularity Visible • Less avoidable scrapping of parts	• Circular Value retention • Supply Chain Resilience • Cross-team alignment on value retain/loss	• Parts are assets, not consumables • Lower OEM dependency • Sustainability as a priority • Collaboration with repair partners
Responsibilities	• Roadmap responsibility owner • Data + reporting building • Overseeing operational implementation • Technical feasibility input • CO_2 viability oversight	• Circular steering owner • Tracking capabilities • Data governance • Operational execution • Finance/procurement involvement • Transformation support	• Ecosystem owner • External partner management • Clear steering of core repair capabilities • Indicator governance • CO_2 tracking governance
success Criteria	• Outcome language adoption • Data quality • Baseline visibility • Decision usage circularity • Governance clarity	• R trend stability • Circular steering adoption • Circular effectiveness • Indicator-based repair decisions • Signal maturity for FFL	• Ecosystem resilience • OEM dependency reduction • Decision integration of indicators • Increased repair performance • Maturity of circular governance

7.6 TACTICAL ROADMAP

The strategic roadmap sets direction across the three horizons, but it does not show what must be built, by whom, and in what order. The tactical roadmap provides that foundation. It translates the horizon storyline into coordinated steps, with clearer sequencing, dependencies, and ownership, so the strategic roadmap is not an isolated vision but an executable plan.

The orange connecting lines highlight dependencies between elements. They show how one element drives the next, making the logic behind choices explicit, clarifying what must come first, and indicating where missing prerequisites would block progress.



This distinction between roadmaps aligns with design roadmapping practice. Tactical roadmaps are aimed at project and program management and use a lane-based structure to connect market needs, product or service development, and enabling technology over time. Their spatial layout is used to communicate timing, follow-up steps, and resourcing (Simonse, 2017).

In this thesis, the strategic roadmap functions as the stakeholder-facing narrative of where E&M aims to go across the horizons, while the tactical roadmap functions as the evidence and implementation logic that makes this progression credible.

The tactical roadmap is structured along the same three horizons as the strategic roadmap, **but it is divided into four themes to keep complexity manageable while preserving system logic** (appendix AA). These themes reflect the main implementation barriers and opportunities identified in the research. Grouping actions this way prevents the roadmap from becoming a long feature list and makes dependencies visible. It also supports program-level coordination, because each theme implies different owners, different resource needs, and different readiness levels, while still contributing to the same end state of circular value retention embedded in MRO decision-making.

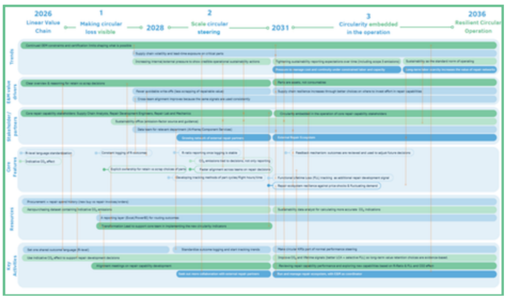


Figure 11: four themes with elaboration, as found on the tactical roadmap page of the website and appendix AA

DECISION GOVERNANCE UNDER HARD CONSTRAINTS

Circular value retention is made steerable by assigning clear ownership and standard decision inputs at key routing gates, so "retain vs scrap" becomes an explicit, auditable choice under safety, warranty, and OEM constraints.

INDICATOR ROLLOUT FOR CIRCULAR STEERING

Circularity is operationalised through a staged indicator rollout that starts with shared outcome language and stable logging, then adds steering signals only once the foundations are trusted.

CO_2 AS TRANSITION-RISK MANAGEMENT

CO_2 is introduced first as a directional repair-versus-replace signal and then matured into governed assumptions, reducing the risk of late, ad-hoc compliance and reporting when Scope 3 expectations tighten.

SCALING THROUGH THE ECOSYSTEM

Circularity at scale requires a managed repair ecosystem that reduces OEM dependence by securing compliant alternatives through qualified partners and in-house repair capabilities.

VIII
Result Check

TAKE AWAYS FROM DELIVER

1. *Adoption depends on governance, standardized outcome language, consistent logging at the source, and fixed review patterns.*
2. *The horizon roadmap prevents overload by step-by-step maturity*
3. *Scaling circularity exposes capacity as the real constraint. Implementation must include partner governance and ecosystem choices to expand repair capability without increasing operational AOG risk.*

8.1 DESIRABILITY/FEASIBILITY/VIABILITY CHECK

Desirability

The blueprint is desirable because the current routing reality is dominated by urgency and incomplete information, so decisions converge on the lowest-risk default (scrap/replace) when constraints surface late or inputs are scattered. **The thesis responds to what stakeholders actually need: a way to make outcomes comparable and therefore discussable beyond one-off cases**, instead of relying on local memory and "who knows what." It becomes desirable because circularity only becomes actionable when expressed in steerable outcomes. The design process explicitly shows the moment this was demanded and uses it as a design requirement, rather than treating circularity as a moral argument.

Feasibility

The blueprint is feasible because the solution is built around the constraints that already govern routing decisions: lead time risk, warranty handling and scaling limits rather than assuming ideal data or ideal capacity. Feasibility is strengthened by the explicit sequencing logic: first establish shared language and stable logging, then move to steering. This prevents the practical failure mode where teams spend time debating numbers instead of using them. The roadmap structure is therefore not "nice to have"; it is the mechanism that keeps early steps lightweight and aligned with existing rhythms before asking the organisation to act on more advanced signals.

Viability

It is viable because adoption is framed as an operating model requirement: persistent use depends on ownership, a fixed review moments and stable assumptions that survive beyond individual champions. The viability logic is grounded in stakeholder statements that circularity will not sustain "on top of the job" without top-down prioritisation and assigned capacity; the work treats that as a boundary condition, not a footnote. Viability is reinforced because the justification is not limited to CO_2; it is tied to resilience and reducing exposure to OEM dependence, scarcity, and long lead times—drivers that remain relevant even when direct financial incentives for embodied emissions are weak.

Blueprint element	Desirable	Feasible	Viable	Main risk + fix
Indicator set	*Shared decision language*	*Easy to understand*	*Owner & review moments*	*Info overload→ staged rollout*
Strategic roadmap	*Align teams on direction*	*Clear dependencies*	*Tied to governance cycle*	*"Just a poster" → linked to concrete actions*
Tactical roadmap	*Makes work executable*	*Owners + sequence*	*Routine in meetings*	*No follow through→ assign ownership*
Website	*Easy to navigate*	*Easy to distribute*	*Link to governance & review rhythm*	*Not visited→ embed in meetings to-do checklist*

Figure 12: Evaluation Matrix Circularity Blueprint

9

CONCLUSION

Circularity can add value in the aviation MRO context of KLM Engineering & Maintenance when it becomes a practical decision discipline: a repeatable way to retain functional and material value in parts, inside the same constraints that already govern MRO (safety, certification, OEM authority, continuity, lead time and cost). In the current system, circular value is often only captured when it aligns with immediate operational logic, while value loss remains largely invisible and therefore hard to steer.

This thesis shows why: routing is a chain of gates, not a single decision and outcomes are strongly shaped by what is known early and who owns the information. The Salvation & Warranty case, in which evidence is grounded, show that decisions are frequently made under time pressure with scattered inputs and late constraints. **When uncertainty is high, the lowest-risk route becomes scrap and replace, even when value could have been retained.**

Embedding circularity therefore starts with making routing outcomes comparable in the language of the operation. The work translates circular economy thinking into part-level outcomes (R-levels) and turns those into a small set of workable signals: a shared outcome language as the foundation, a trend signal (R-ratio) to see recurring loss, and more advanced signals (Functional Lifetime Loss and indicative CO_2) only when governance and assumptions are stable enough to avoid data debates.

With that, circularity adds value in three ways that match E&M priorities. First, it **reduces avoidable value loss** by turning ad-hoc case decisions into reviewable patterns. Second, it **improves resilience** by guiding repair capability development with recurring low-retention outcomes and scarcity risk, instead of only reacting to urgent shortages. Third, it **improves future readiness** by adding CO_2 as a controlled secondary steering signal, introduced only after the circular outcome language and governance are stable enough to keep it decision-useful.

Circularity becomes real in MRO through implementation, not ambition: clear ownership, consistent logging, fixed review routines and a stepwise implementation from visibility to steering to scaling, captured in the Circular Blueprint so it can be used across teams under daily operational pressure.

10 DISCUSSION

This thesis positions circularity in the MRO context as a decision discipline problem rather than an awareness problem: value is lost when routing choices must be made under time pressure, distributed ownership, and incomplete or late information, which makes scrap/replace the safest defensible default even when retention could be possible. The core contribution is therefore not a single metric, but an integrated Blueprint (indicators, roadmaps, and a distributable format) that turns circularity into comparable outcomes so decisions can be reviewed as patterns and improved systematically over time.

A key discussion point is how the indicator set is intentionally built as a maturity chain. Rather than claiming high precision from day one, the work argues that circular steering becomes meaningful only when the organisation can first align on definitions and logging routines. This directly supports the adoption reality described in the thesis: circularity proposals are only resourced when translated into steerable outcomes that management can recognise and weigh against other priorities, and when the method does not trigger recurring debates about what the numbers mean. The staged horizon logic is therefore not a presentation device; it is the mechanism that protects early adoption by keeping the first steps lightweight while explicitly preparing the conditions needed for later steering.

Finally, the roadmap work reframes viability: long-term adoption depends on whether the Blueprint becomes part of existing routines and governance rhythms, not whether it is well received once. This aligns with the thesis' broader argument that circularity in this setting must be implemented as an operating logic with ownership and cadence, because it will not sustain as extra work "on top of the job" within KLM Engineering & Maintenance.

11 LIMITATIONS

The work is a qualitative case focused on Salvation & Warranty and related routing decisions. This means the insights may not translate directly to other MRO domains with different certification constraints, warranty rules, or criticality. The evidence is mainly based on interviews, follow-ups, and a workshop, because decision rules are often implicit and spread across roles; this was useful to reconstruct the gate logic and constraints, but it does not allow statistical claims or measured impact.

A second limitation is that some indicators can easily suggest more certainty than the data currently supports. Steering depends on stable definitions and consistent logging; before that is in place, signals can be incomplete or open to interpretation. The roadmap addresses this by introducing indicators in stages, but this thesis does not yet show how they perform over multiple cycles in a live pilot.

A third limitation is that the proposed approach is evaluated mainly through expert feedback and design reasoning rather than through a full operational trial, so real-world effects on routing outcomes, workload, and decision speed are not yet demonstrated. A related limitation is that the thesis necessarily simplifies a complex decision context (e.g., by structuring cases into part families and gate logic), which supports steering but may miss edge cases that only become visible at scale or under unusual operational conditions.

12 RECOMMENDATIONS

Recommendations for KLM E&M

Make the Blueprint an operating routine, not a reference document. Adoption depends on whether circularity work survives daily time pressure, distributed ownership, and late-surfacing constraints that currently push decisions toward the safest default. Embed use into existing decision moments and gate conversations, so it is pulled by the process rather than pushed as guidance.

Assign explicit ownership and cadence before expanding indicator ambition. The thesis logic already shows that steering is only credible after definitions and logging are stable; without governance, indicators drift into debate and stop being used. Create one accountable owner for definitions and change control, and one fixed review rhythm for decisions and follow-up. Treat this as a viability precondition, not a later "improvement."

Start with a bounded pilot that proves workability under real constraints. Keep the pilot small enough that it fits the Salvation & Warranty reality and can be executed with current information quality, but concrete enough to force decisions on minimum data fields, meeting insertion point, and success criteria. This converts feasibility from an argument into demonstrated practice in the same environment where defaults currently dominate.

Stabilise logging as the first implementation deliverable. Treat "consistent logging and shared definitions" as Horizon 1 output, because everything else depends on it. Only after this foundation exists do time-based signals and prioritisation logic become meaningful; otherwise the organisation will revert to case-by-case reasoning.

Keep the management rationale anchored in steerable outcomes. The thesis documents that circularity gained traction only when translated into outcomes that can be prioritised and resourced, rather than framed as intent. Maintain that framing: connect the work to value loss reduction and to decision-grade steering signals, and avoid overclaiming precision where assumptions are still maturing.

Institutionalise website use inside the repair capability check. The website format only creates value if it is used in routine decisions. Make consulting it a standard step in the repair capability check, so it becomes part of the gate logic rather than an optional artefact.

Recommendations for Designers and Circular Practitioners

Design from the decision funnel outward. In regulated, high-pressure operations, circularity fails when it is not defensible at the moment a routing choice is made. Start by reconstructing real gate logic and the "safe default" behaviours, then design interventions that fit those moments.

Treat metrics as a maturity chain, not a single solution. Avoid false precision early. First create shared definitions and stable logging, then introduce steering signals, and only then add advanced measures that depend on governed assumptions. This preserves credibility and prevents measurement discussions from replacing action.

Translate circularity into the organisation's existing trade-off language. Circularity becomes actionable when expressed in steerable outcomes that management can resource and weigh. Keep the narrative grounded in what stakeholders already decide on, rather than adding a parallel value system that will not be prioritised.

Treat adoption as operating model design. Viability is created through ownership, cadence, and governance, not through a better dashboard. Design the roles, review rhythm, and change-control for definitions as part of the deliverable, because "on top of the job" implementations do not persist.

Use deliverable format as a boundary object, but keep the thesis and logic self-sufficient. Interactive artefacts help cross-team alignment, yet the core reasoning must remain auditable without external access. Make the format support adoption, while the argument stays reproducible through traceability between findings, requirements, and implementation choices.


ONE ACCURATE MEASUREMENT IS WORTH A THOUSAND EXPERT OPINIONS
Grace Hopper -
pioneering American computer scientist and US Navy Rear Admiral

14 SOURCES

Aircraft maintenance | AIR FRANCE KLM. (n.d.). Retrieved January 23, 2026, from https://www.airfranceklm.com/en/our-strengths/aircraft-maintenance

Atasu, D., van Wassenhove. (n.d.). The Circular Business Model. Harvard Business Review. Retrieved https://hbr.org/2021/07/the-circular-business-model

Bakker, et al., den Hollander, M., Peck, D., & Balkenende, R. (2019). Critical Materials: Underlying Causes and Sustainable Mitigation Strategies (Vol. 05). WORLD SCIENTIFIC. https://doi.org/10.1142/11007

Bibri, S. E. (2018). Backcasting in futures studies: A synthesized scholarly and planning approach to strategic smart sustainable city development. European Journal of Futures Research, 6(1), 13. https://doi.org/10.1186/s40309-018-0142-z

Bocken, N. M. P., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Component Adaptive Solutions. (n.d.). Airfrance KLM Industries.

Costanza, D., Prentice, B., & Sargent, S. (n.d.). Turbulence in MRO Growth. Oliver Wyman. Retrieved https://www.oliverwyman.com/content/dam/oliver-wyman/v2/publications/2024/mar/MRO-Survey-2024-Aviation-MRO-Growth-Amid-Turbulence.pdf

Den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. Journal of Industrial Ecology, 21(3), 517–525. https://doi.org/10.1111/jiec.12610

Design methods for developing services. (n.d.). Design Council. Retrieved https://www.designcouncil.org.uk/fileadmin/uploads/dc/Documents/DesignCouncil_Design%2520methods%2520for%2520developing%2520services.pdf

European Union Aviation Safety Agency. (2025). European aviation environmental report 2025. Publications Office. https://data.europa.eu/doi/10.2822/1537033

Geissdoerfer, M., Morioka, S. N., De Carvalho, M. M., & Evans, S. (2018). Business models and supply chains for the circular economy. Journal of Cleaner Production, 190, 712–721. https://doi.org/10.1016/j.jclepro.2018.04.159

Hallensleben, C., Albers, S., & Dewulf, W. (2025). Strategic bottlenecks in commercial aviation MRO: OEM influence and the response of traditional maintenance providers. Journal of the Air Transport Research Society, 5, 100084. https://doi.org/10.1016/j.jatrs.2025.100084

IATA global-outlook-for-air-transport-june-2025. (n.d.). The International Air Transport Association (IATA). Retrieved https://www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport-june-2025/
Jonker, J., Faber, N., & Haaker, T. (n.d.). Quick Scan Circular Business Models.

Kazancoglu, I., Sagnak, M., Kumar Mangla, S., & Kazancoglu, Y. (2021). Circular economy and the policy: A framework for improving the corporate environmental management in supply chains. Business Strategy and the Environment, 30(1), 590–608. https://doi.org/10.1002/bse.2641

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the Circular Economy: Evidence From the European Union (EU). Ecological Economics, 150, 264–272. https://doi.org/10.1016/j.ecolecon.2018.04.028

KLM-Annual-Report-2024. (2024). KLM Head Office. https://www.klmannualreport.com/

KLM-Climate-Action-Plan. (2023). KLM Head Office. https://img.static-kl.com/m/7b0b0f3946d5bb53/original/KLM-Climate-Action-Plan.pdf

KPMG Circularity in Flight: The potential for aircraft and the circular economy. (n.d.). KPMG. Retrieved https://assets.kpmg.com/content/dam/kpmg/ie/pdf/2024/03/ie-aviation-circular-economy-tl.pdf

Lewandowski, M. (2016). Designing the Business Models for Circular Economy—Towards the Conceptual Framework. Sustainability, 8(1), 43. https://doi.org/10.3390/su8010043

Liangrokapart, J., & Sittiwatethanasiri, T. (2023). Strategic direction for aviation maintenance, repair, and overhaul hub after crisis recovery. Asia Pacific Management Review, 28(2), 81–89. https://doi.org/10.1016/j.apmrv.2022.03.003

Linder, M., Sarasini, S., & Van Loon, P. (2017). A Metric for Quantifying Product-Level Circularity. Journal of Industrial Ecology, 21(3), 545–558. https://doi.org/10.1111/jiec.12552

Linder, M., & Williander, M. (2017). Circular Business Model Innovation: Inherent Uncertainties. Business Strategy and the Environment, 26(2), 182–196. https://doi.org/10.1002/bse.1906

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). Qualitative data analysis: A methods sourcebook (Edition 3). Sage.

Montag, L., & Pettau, T. (2022). Process performance measurement framework for circular supply chain: An updated SCOR perspective. Circular Economy. https://doi.org/10.55845/KAIZ3670

Oliver Wyman. (n.d.). Global Fleet and MRO Market Forecast 2025-2035

Opties voor scope 3-beleid in Nederland TNO. (2024, April 29). TNO. https://publications.tno.nl/publication/34642211/Wzac4r/TNO-2024-P10473.pdf

Paletti, L., Markatos, D., Filippatos, A., & Pantelakis, S. (2025). Towards a Reference Framework of Practices to Align Aviation with the Circular Economy ISO 59004:2024 Standard. Journal of Circular Economy, 3(3). https://doi.org/10.55845/BMAF1243

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (n.d.). CIRCULAR ECONOMY: MEASURING INNOVATION IN THE PRODUCT CHAIN.

Powell, T., & Sammut-Bonnici, T. (n.d.). Wiley Encyclopedia of Management. In Wiley Encyclopedia of Management. https://doi.org/10.1002/9781118785317.weom120202 (Original work published 2015)

Regulation (EU) 2018/1139 of the European Parliament and of the Council. (2023). https://www.easa.europa.eu/en/downloads/107247/en

Reike, D., Vermeulen, W. J. V., & Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resources, Conservation and Recycling, 135, 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Russell, J. D., Nasr, N. Z., & UNEP International Resource Panel. (2018). Re-Defining Value - The Manufacturing Revolution: Remanufacturing, Refurbishment, Repair and Direct Reuse in the Circular Economy. https://doi.org/10.13140/RG.2.2.31020.00640

Sanders, E. B.-N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. CoDesign, 4(1), 5–18. https://doi.org/10.1080/15710880701875068

Simonse, L. W. L. (2017). Design roadmapping (J. Whelton, Ed.). Bis Publishers.

Six steps to get the best data quality in your modern data platform. (2025). [Columbus Global]. https://www.columbusglobal.com/insights/articles/six-steps-to-get-the-best-data-quality-in-your-modern-data-platform/

Spherical Insights. (2025, September). Top 50 Companies in Aircraft Maintenance, Repair, and Overhaul (MRO) Market [Research Report]. https://www.sphericalinsights.com/blogs/top-50-companies-in-aircraft-maintenance-repair-and-overhaul-mro-market-statistics-report-till-2035

Sterman, J. (2015). Booms, Busts, and Beer. In E. Bendoly, W. Van Wezel, & D. G. Bachrach (Eds.), The Handbook of Behavioral Operations Management (pp. 203–237). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199357215.003.0011

The Aircraft big data explosion: How much is enough? (2021, January). Aircraft Commerce Issue No. 133. https://www.aircraft-commerce.com/wp-content/uploads/aircraft-commerce-docs/General%20Articles/2020/133_FLTOPS_A.pdf

Ting, H., Thurasamy, R., & Cheah, J.-H. (2025). Snowball Sampling: A Review and Guidelines for Survey Research. Asian Journal of Business Research, 15(1), 1–15. https://doi.org/10.14707/ajbr.250186

van Boeijen, A., & Daalhuizen, J. (2010). Delft Design Guide.

Voulgaridis, K., Lagkas, T., Angelopoulos, C. M., Boulogeorgos, A.-A. A., Argyriou, V., & Sarigiannidis, P. (2024). Digital product passports as enablers of digital circular economy: A framework based on technological perspective. Telecommunication Systems, 85(4), 699–715. https://doi.org/10.1007/s11235-024-01104-x

Wörner, D., Falcke, L., Ritter, M., West, S., & Friedli, T. (2025). Open Innovation for Circular Business Models: Addressing the Right Challenge at the Right Time. Journal of Product Innovation Management, jpim.70004. https://doi.org/10.1111/jpim.70004