Online Resource 2 — Supplementary Material

When can remanufacturing make Car-as-a-Service financially viable? A life-cycle costing assessment for passenger vehicles

Ahmed S. Alghamdi — Jubail Industrial College, Jubail, Saudi Arabia — ghamdi_as@rcjy.edu.sa

S1. Contents

This document accompanies the manuscript and the open spreadsheet implementation (Online Resource 1, ESM_1.xlsx). Section S2 states the model in full, including the derivation of the break-even fees used in Sections 5.2–5.4 of the manuscript. Section S3 documents every input parameter, its evidentiary status and its source. Section S4 describes the spreadsheet workbook. Section S5 gives step-by-step instructions to reproduce every figure and table in the manuscript.

S2. Full model statement and derivations

Notation follows the manuscript's Nomenclature. Both business models are evaluated over K consecutive use cycles of equal length L (months) for a single representative vehicle. All cash flows are discounted at the provider's annual cost of capital r; the user is assigned the same rate, a simplification discussed in the manuscript (Section 3.5).

S2.1 Discounting. The monthly rate, monthly discount factor and cycle discount factor are:

$$r_m = (1 + r)^{1/12} - 1, \quad v = 1/(1 + r_m), \quad v_L = v^L \tag{S1}$$

A constant monthly amount a paid at the end of each month of one cycle has present value $a \cdot A(L)$ at the cycle start, and the start of cycle k (k = 0, …, K−1) is discounted by v_L^k. Hence:

$$A(L) = (1 - v_L)/r_m, \quad S_K = \Sigma_{k=0}^{K-1} v_L^k \tag{S2}$$

S2.2 Provider cash flows. Under Sales, the provider sells one new vehicle at the start of each cycle, earning the margin $S_N - C_{Mf} - C_{cs}$ each time:

$$NPV_{prov}^{Sales} = (S_N - C_{Mf} - C_{cs}) \cdot S_K \tag{S3}$$

Under PaaS, the provider manufactures once (cycle 0), reconditions the returned core at the start of each subsequent cycle, incurs a setup cost C_{cl} per cycle, collects the fee F monthly, bears the monthly running costs (maintenance C_M, repair C_{rl}, management C_a, insurance C_{ins}), and at the end of the horizon realises the terminal core value ρS_N net of recycling C_{rc}:

$$NPV_{prov}^{PaaS} = (F - C_M - C_{rl} - C_a - C_{ins}) \cdot A(L) \cdot S_K - (C_{Mf} + C_{cl}) - \Sigma_{k=1}^{K-1}(C_{Rf} + C_{cl}) \cdot v_L^k + (\rho S_N - C_{rc}) \cdot v_L^K \tag{S4}$$

S2.3 User cash flows. Under Sales, the user buys a vehicle at the start of each cycle, recovers the residual γS_N at its end, and pays maintenance, repair and insurance monthly; under PaaS the user pays only the fee:

$$TCO_{user}^{Sales} = S_N \cdot S_K - \gamma S_N \cdot v_L \cdot S_K + (C_M + C_{rl} + C_{ins}) \cdot A(L) \cdot S_K \tag{S5}$$

$$TCO_{user}^{PaaS} = F \cdot A(L) \cdot S_K \tag{S6}$$

S2.4 Equivalent annual annuity. For comparison across horizons, any aggregate X over K cycles ($T = K \cdot L/12$ years) is annualised as:

$$EAA(X) = X \cdot r / (1 - (1 + r)^{-T}) \tag{S7}$$

S2.5 Break-even fees (derivation). The user maximum acceptable fee F_u equates Eqs. (S5) and (S6). Dividing by $A(L) \cdot S_K$:

$$F\_u = S\_N(1 - \gamma \cdot v\_L)/A(L) + C\_M + C\_rl + C\_ins \quad (S8)$$

The provider break-even fee F_p equates Eqs. (S3) and (S4). Solving Eq. (S4) = Eq. (S3) for F:

$$F\_p = [NPV\_prov\text{^}Sales + (C\_Mf + C\_cl) + \Sigma\_\{k=1\}\text{^}\{K-1\}(C\_Rf + C\_cl)v\_L\text{^}k - (\rho S\_N - C\_rc)v\_L\text{^}K] / [A(L) \cdot S\_K] + C\_M + C\_rl + C\_a + C\_ins \quad (S9)$$

A win-win fee window exists iff F_p ≤ F_u. Subtracting Eq. (S8) from Eq. (S9), the running costs C_M, C_rl and C_ins cancel identically—they enter both fees with coefficient one—which proves the invariance stated in Section 5.4 of the manuscript: the fee gap, and hence the win-win conclusion, does not depend on the benchmarked maintenance, repair or insurance inputs. The gap depends on manufacturing and reconditioning cost, the residual parameters γ and ρ, the management cost C_a, and the discounting structure. At base-case values (Table S1), F_p = EUR 699/month and F_u = EUR 624/month (K = 3), a gap of EUR 75/month.

S3. Parameter documentation and sources

Each input is tagged PUBLIC (a real, publicly documented figure), BENCHMARK (a defensible industry or market benchmark), or ASSUMPTION (an estimate with weak public data, treated as a primary target of the sensitivity analysis). Sources were accessed in 2026.

Sym.	Parameter	Value	Type	Source / justification
r	Discount rate (annual)	6.5%	PUBLIC-deriv.	Third-party estimates of Toyota Motor's weighted average cost of capital cluster at ~6.0–7.0% (Alpha Spread; valueinvesting.io), 2025–26. Midpoint used.
L	Use-cycle length	36 mo	PUBLIC	KINTO ONE standard three-year contract (Toyota Motor Corp. global newsroom, 2019; KINTO service pages, 2025).
S_N	New-vehicle price	EUR 30,000	BENCHMARK	Representative European C-segment (Corolla-class) transaction price.
F	Subscription fee	EUR 480/mo	BENCHMARK	Anchored on published KINTO ONE Japan fee from ¥54,340/mo (≈EUR 330; Toyota newsroom) and European C-segment full-service-lease rates incl. insurance and maintenance (~EUR 400–550/mo).
γ	Residual value at 3 yr	57% of S_N	BENCHMARK	Corolla-class three-year resale retention ~55–60% (industry residual-value benchmarks).
ρ	Terminal residual (provider)	25% of S_N	ASSUMPTION	Used/salvage value of the retained core at horizon end.
C_Mf	Manufacturing cost	EUR 22,500	ASSUMPTION	~75% of S_N as illustrative unit COGS; a primary sensitivity target (Table 3 of the manuscript).
C_Rf	Reconditioning cost	EUR 3,500	ASSUMPTION	Cost to restore a returned core to certified-pre-owned grade for the next cycle.

C_cs	Sales commission	EUR 900	ASSUMPTION	~3% of S_N dealer/sales commission (Sales model).
C_cl	Subscription setup	EUR 300	ASSUMPTION	Per-cycle acquisition/contract setup cost (PaaS).
C_M	Maintenance	EUR 45/mo	BENCHMARK	Scheduled maintenance for C-segment ICE ~EUR 500–600/yr; cancels from the fee gap (S2.5).
C_rl	Repair (expected)	EUR 20/mo	BENCHMARK	Expected non-warranty repair provision; cancels from the fee gap (S2.5).
C_a	Subscription management	EUR 60/mo	ASSUMPTION	Fleet operations, telematics, remarketing and administration per vehicle; the least publicly documented driver.
C_ins	Insurance	EUR 75/mo	BENCHMARK	Comprehensive cover ~EUR 900/yr; cancels from the fee gap (S2.5).
C_rc	Recycling/disposal	EUR 300	ASSUMPTION	End-of-life handling of the core at horizon end.

Table S1. Complete input documentation. “PUBLIC-deriv.” denotes a value derived from public third-party estimates rather than a company disclosure.

S4. The spreadsheet workbook

Online Resource 1 (ESM_1.xlsx) implements the model with live formulas and no macros. Sheet ‘Inputs & Sources’ holds every parameter of Table S1 (blue cells; edit these). Sheet ‘Model (base case)’ builds the per-cycle present values, the provider NPV and user TCO for K = 1, 2, 3, the EAA values, and the win-win test, implementing Eqs. (S1)–(S8). Sheet ‘Scenarios’ evaluates the intervention columns of Section 5.3 with per-column overrides of fee, management cost and cycle length. The manuscript's closed-form results were verified cell-by-cell against this workbook (all values agree to rounding).

S5. Reproducing the manuscript's results

Table 2: open ‘Model (base case)’; rows ‘Provider NPV’ and ‘User TCO’ give the K = 1, 2, 3 values; F_p and F_u follow from Eqs. (S8)–(S9) at base inputs. Fig. 1: chart the same rows. Fig. 2: vary F over 0.6–1.6× base in ‘Inputs & Sources’ and record the two PaaS-to-Sales ratios at K = 3. Fig. 3: repeat for C_a over 0–2× base. Fig. 4: evaluate F_p − F_u from Eqs. (S8)–(S9) on a grid of L ∈ [24, 72] months and C_a ∈ [0, 90] EUR/month; the contour F_p = F_u bounds the win-win-feasible region. Table 3: perturb each parameter of Table S1 by ±25% one at a time and record F_p − F_u; maintenance, repair and insurance leave the gap unchanged by the cancellation shown in S2.5. Section 5.3 combined scenarios: use the ‘Scenarios’ sheet columns, or set (L = 48, C_a = 30, F = 528) and (L = 60, C_a = 20, C_Rf = 2,000) in the inputs sheet.

All computations are deterministic; no random seeds are involved. Any spreadsheet application supporting standard functions reproduces the results identically.