Repairable fleet — repairs per machine by age, and whether the fleet wears

Menu: Life Data ▸ Repairable Fleet...

Part 1 — What the function does

What it calculates. A fleet of like machines is repaired and put back to work after each failure. From one row per repair - the machine, its age at the repair, and the age at which you stopped watching it - ReliaEn draws the mean cumulative function (MCF): the average number of repairs per machine by each age, with bounds, no model assumed. It fits one power law to the whole fleet, the expected repairs per machine by age t being λ·t^β, tests whether β = 1, checks whether one β fits every machine, and, with an overhaul cost and a failure cost, gives the cheapest overhaul age.

What ReliaEn prints	What it tells you
MCF staircase and life table, with bounds	The fleet's actual repair history: mean repairs per machine by age
Pooled β (fleet shape) with bounds, **Pooled λ**	β below 1: repairs spacing out; about 1: stable; above 1: bunching up (wearing)
MTBF now and **MTBF cumulative**, per machine	The time between repairs at the longest age, and on average
Trend verdict (growth test), Laplace and Anderson-Darling tests	Whether the data can tell the fleet from a stable one
Per-machine fits + common-β verdict	Whether one β describes every machine, so pooling is defensible
Overhaul optimization (with the two costs)	The overhaul age with the lowest cost per hour, and the saving

From which data. One worksheet row per repair: the machine identifier, the machine's age at the repair, and the machine's observation end, repeated on each of its rows. A repair cost column and a second fleet for comparison are optional.

When an engineer uses it. When a group of repairable machines of one type has a repair log, and the questions are whether repairs come faster as the machines age, and whether a planned overhaul age pays.

When not to use it.

Situation	Use instead
The log of one machine only, and the renewal MTBF with its interval is wanted	Life Data ▸ Estimate Failure Function ▸ Repairable unit data...
Each failed item is replaced by a new one, and its age at failure is known	Life Data ▸ Time Dependence ▸ Weibull (2P) distribution...
How much a repair restores the machine is the question	Life Data ▸ Repairable Systems ▸ GRP / Kijima...

Part 2 — The example's input data

Setting. A plant has three compressors with records of different length: M1 watched to 800 hours, M2 to 500 hours, M3 to 900 hours. Nine repairs are logged. The planned overhaul costs 4,000 and an unplanned failure repair 25,000. The reliability engineer wants to know whether the compressors wear and whether an overhaul age pays.

Input	Value
M1: repair ages, hours (end 800)	120, 340, 610
M2: repair ages, hours (end 500)	90, 450
M3: repair ages, hours (end 900)	200, 380, 560, 720
Overhaul cost Cp / Failure cost Cf	4,000 / 25,000
File in the worked-example zip	3-Repairable-Fleet/Example-2.csv — columns Machine, Age and End, 9 rows

	① A	② B	③ C	D
1	M1	120	800	
2	M1	340	800	
3	M1	610	800	
4	M2	90	500	
5	M2	450	500	
6	M3	200	900	
7	M3	380	900	
8	M3	560	900	
9	M3	720	900	
10				

The example data in the worksheet

- ① Column A: the machine of each repair, M1 to M3.
- ② Column B: the age at the repair, in hours.
- ③ Column C: the machine's observation end, on each of its rows.

Part 3 — How to use it, step by step

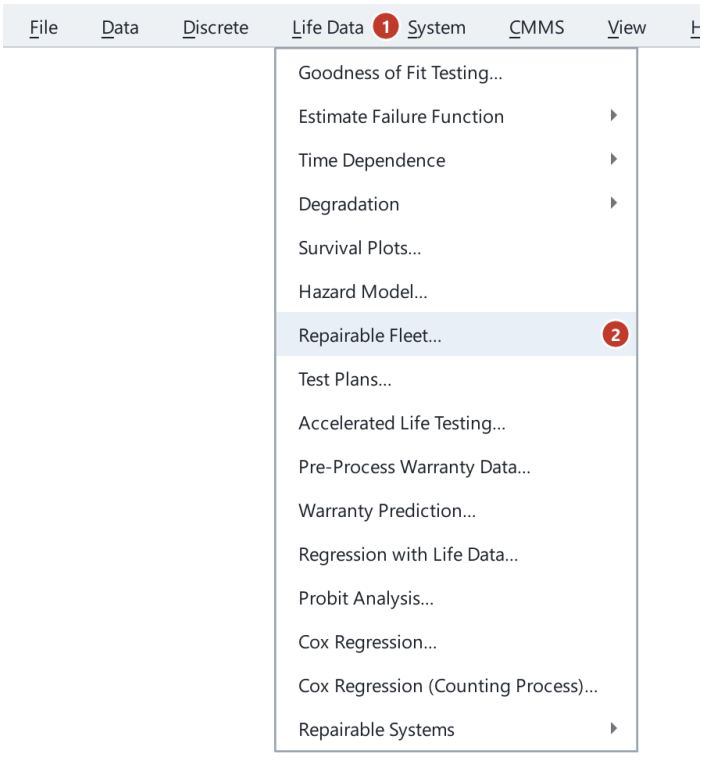
1. **Put the repair log in columns A to C.** Copy the 9 rows of Example-2.csv - its columns Machine, Age and End - into columns A, B and C of the worksheet, starting at row 1: one row per repair.

	① A	② B	③ C	D
1	M1	120	800	
2	M1	340	800	
3	M1	610	800	
4	M2	90	500	
5	M2	450	500	
6	M3	200	900	
7	M3	380	900	
8	M3	560	900	
9	M3	720	900	
10				

Step 1 — the repair log in columns A to C

- ① Column A: the machine of each repair, M1 to M3.
- ② Column B: the age at the repair, 90 to 720 hours.
- ③ Column C: the machine's observation end on each of its rows - 800, 500 and 900 hours.

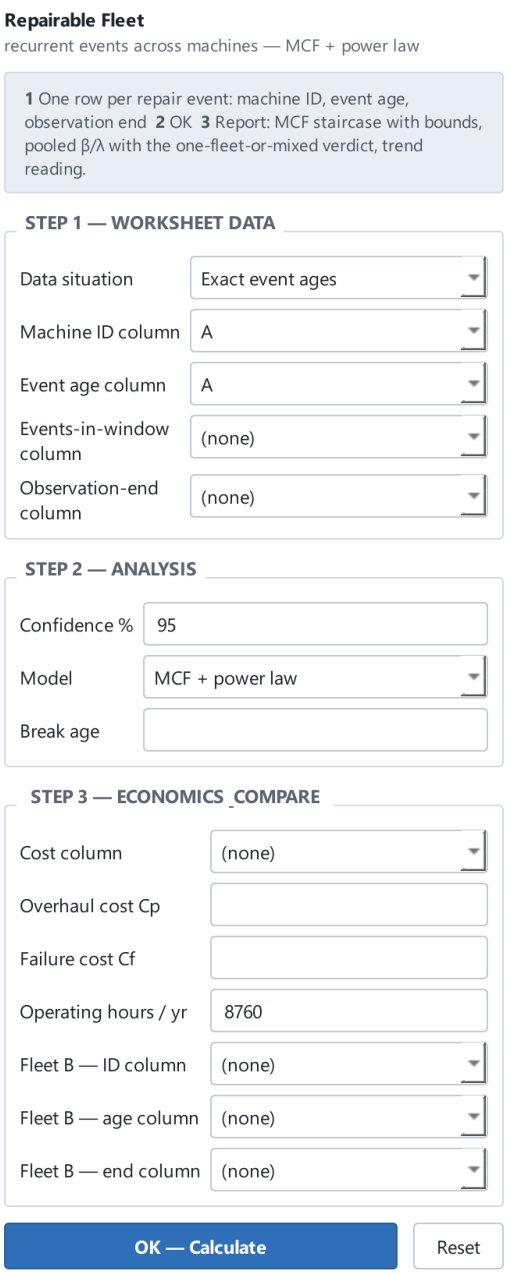
2. **Choose Life Data ▸ Repairable Fleet...** in the menu bar. The form Repairable Fleet opens in the left panel.



Step 2 — the menu path

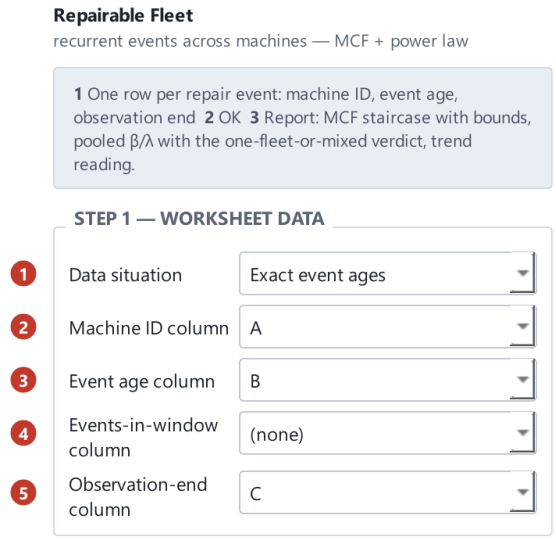
- ① Life Data: the menu.
- ② Repairable Fleet...: the entry to click.

The form as it opens, before any box is set:

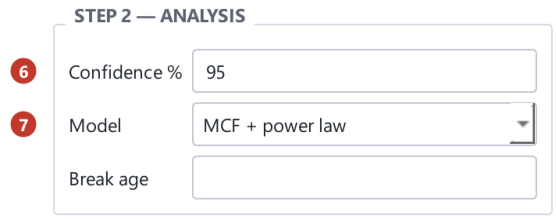


Step 2 — the form as it opens

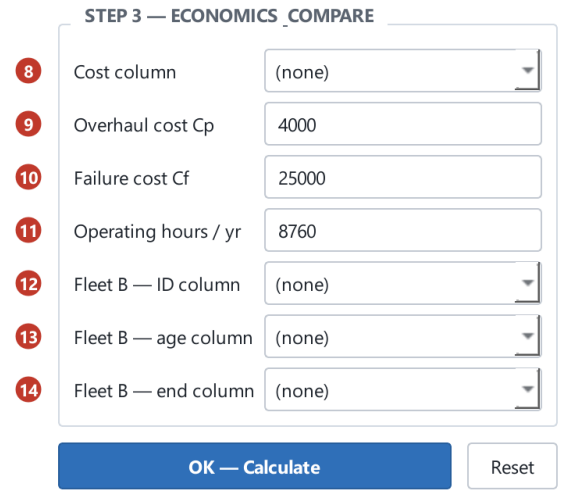
Steps 3 to 16 set or check the form's fourteen boxes, shown in three pictures, one per group of the form - ① to ⑤, ⑥ and ⑦, ⑧ to ⑭:



Steps 3 to 7 — the worksheet boxes set for this example



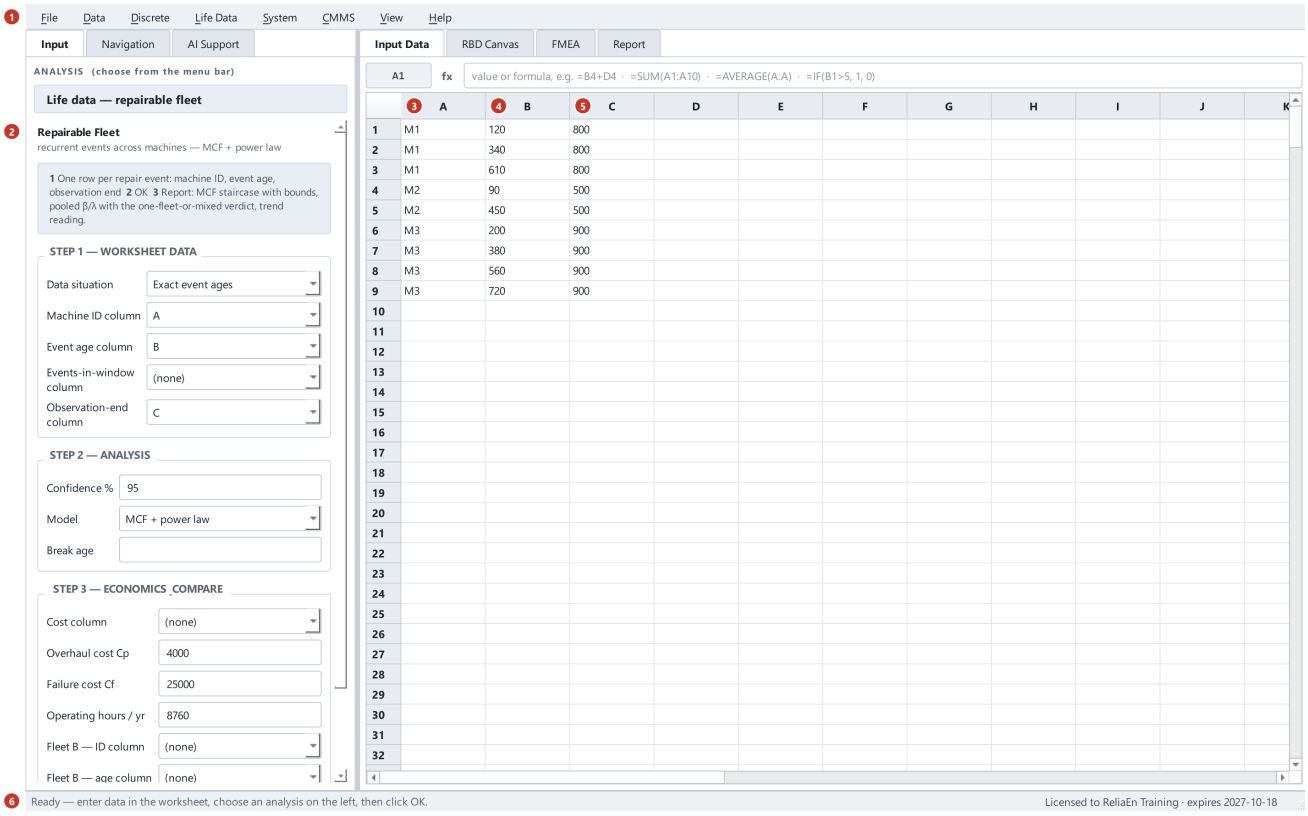
Steps 8 and 9 — the analysis boxes



Steps 10 to 16 — the cost boxes set for this example

3. ① **Check that Data situation reads Exact event ages.**
4. ② **Check that Machine ID column reads A.**
5. ③ **In Event age column, choose B.**
6. ④ **Check that Events-in-window column reads (none).** It is for counts per inspection window, not for exact ages.
7. ⑤ **In Observation-end column, choose C.** Each machine's record ends there; without it the record would end at its last repair.
8. ⑥ **Check that Confidence % reads 95.**
9. ⑦ **Check that Model reads MCF + power law.** Break age below it stays empty.
10. ⑧ **Check that Cost column reads (none).**
11. ⑨ **In Overhaul cost Cp, type 4000.**
12. ⑩ **In Failure cost Cf, type 25000.**
13. ⑪ **Check that Operating hours / yr reads 8760.** It turns the saving per hour into a saving per year.
14. ⑫ **Check that Fleet B — ID column reads (none).**
15. ⑬ **Check that Fleet B — age column reads (none).**
16. ⑭ **Check that Fleet B — end column reads (none).** The three Fleet B boxes compare a second fleet; this example has one.

17. **Click OK — Calculate** at the foot of the form (② in the picture below). ReliaEn calculates and shows the report.



Step 17 — the window just before OK

- ① The menu bar: File, Data, Discrete, Life Data, System, CMMS, View, Help.
- ② The form, set as in steps 3 to 16; OK — Calculate at its foot.
- ③ Column A: the machines.
- ④ Column B: the repair ages.
- ⑤ Column C: the observation ends.
- ⑥ The status bar: Ready — enter data in the worksheet, choose an analysis on the left, then click OK. and Licensed to ReliaEn Training · expires 2027-10-18.

Part 4 — The report, card by card

Life Data — Repairable Fleet

```
2026-11-04 07:18:20
MCF: ΔMCF = d/r per event age ; power law: E[N(t)] = λt^β, β̂ = N/ΣΣ ln(T_q/t_iq)
```

The report's head

- The title Life Data — Repairable Fleet, the date and time of the run, and the two models in one line: MCF: ΔMCF = d/r per event age; power law: E[N(t)] = λt^β, β̂ = N/ΣΣ ln(T_q/t_iq).

INPUT DATA

1	Fleet	`3 machines, 9 repair events`
2	Observation windows	`to age 900 (longest)`
3	Confidence level	`95%`
4	Model	`MCF + power law`

Input data

- ① Fleet 3 machines, 9 repair events.
- ② Observation windows to age 900 (longest): M3's record.
- ③ Confidence level 95%.
- ④ Model MCF + power law.

RESULTS

1	Pooled β (fleet shape)	`1.1381 [0.5204, 1.9933]`
2	Pooled λ (per machine)	`0.001638 (SE 0.0005459) [0.0007489, 0.003109] — conditional on the fitted shape`
3	MTBF now — instantaneous, per machine	`209.7`
4	MTBF cumulative, per machine	`238.7`
5	Trend verdict	`no-trend (growth test p = 0.789)`
6	Laplace trend test	`u = -0.0437, p = 0.9652`
7	Anderson-Darling trend test	`A² = 0.2595, p = 0.9652 (asymptotic)`
8	MCF at the last event	`3.500 repairs/machine by age 720`

Results

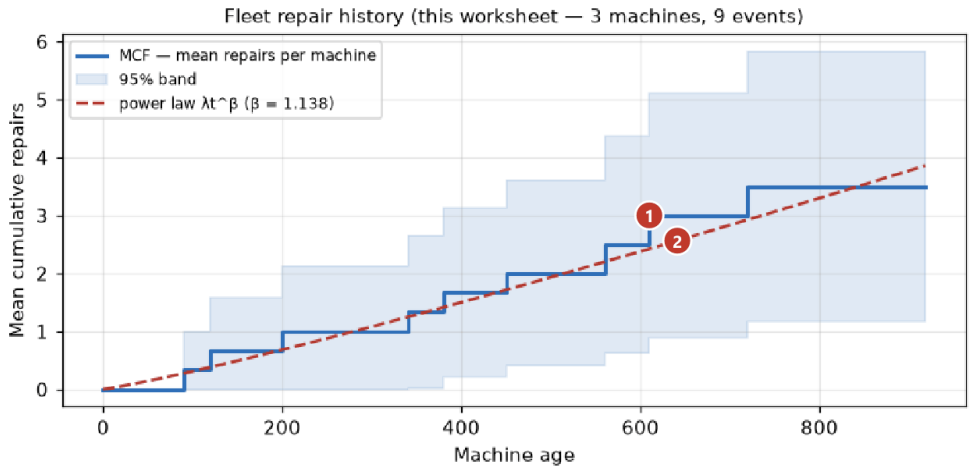
- ① Pooled β (fleet shape) 1.1381 [0.5204, 1.9933]: the bounds contain 1.
- ② Pooled λ (per machine) 0.001638 (SE 0.0005459) [0.0007489, 0.003109] — conditional on the fitted shape.
- ③ MTBF now — instantaneous, per machine 209.7.
- ④ MTBF cumulative, per machine 238.7.
- ⑤ Trend verdict no-trend (growth test p = 0.789).
- ⑥ Laplace trend test u = -0.0437, p = 0.9652.
- ⑦ Anderson-Darling trend test A^2 = 0.2595, p = 0.9652 (asymptotic) - the same p as the Laplace test here, by coincidence.
- ⑧ MCF at the last event 3.500 repairs/machine by age 720.

INTERPRETATION

1 The staircase is the fleet's actual repair history — mean repairs per machine vs age, no model assumed; the risk set shrinks as shorter observation windows end. The power-law curve is the pooled fit over every machine: β < 1 means repairs are spacing out (improving), β > 1 means they are bunching up (wearing), β ≈ 1 means a stable fleet where renewal analysis applies.

Interpretation

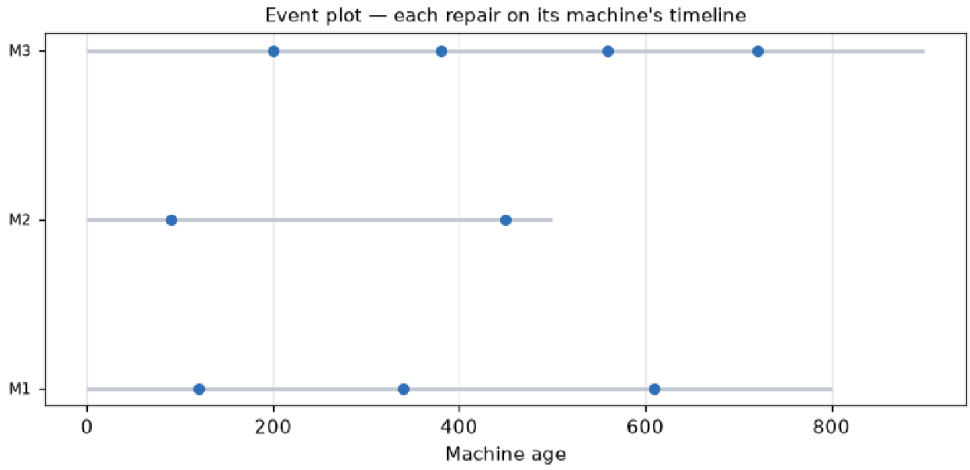
- ① ReliaEn's reading: The staircase is the fleet's actual repair history — mean repairs per machine vs age, no model assumed; the risk set shrinks as shorter observation windows end. The power-law curve is the pooled fit over every machine: β < 1 means repairs are spacing out (improving), β > 1 means they are bunching up (wearing), β ≈ 1 means a stable fleet where renewal analysis applies.



Interactive Plot

Fleet repair history (this worksheet — 3 machines, 9 events)

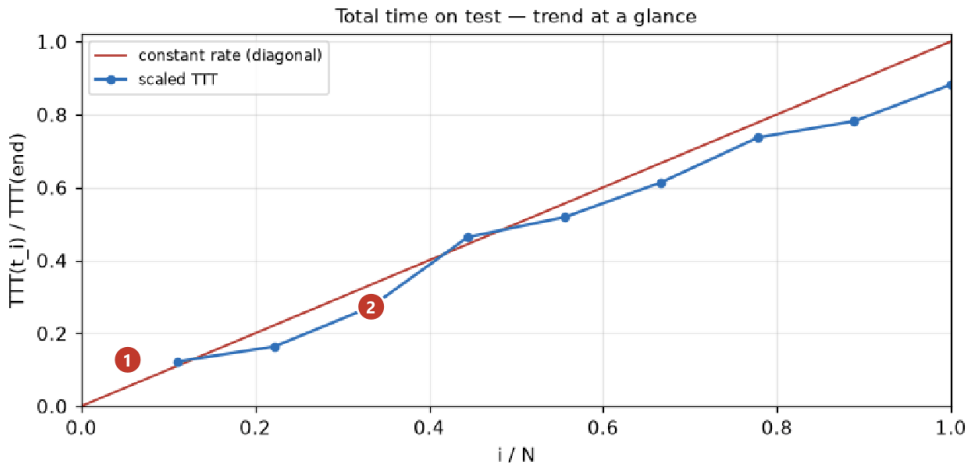
- ① MCF — mean repairs per machine: the staircase, with its 95% band shaded.
- ② power law λt^β (β = 1.138): the pooled fit, close to a straight line.



Interactive Plot

Event plot — each repair on its machine's timeline

- Each machine's record as a grey line to its observation end, each repair as a dot: M2's record stops at 500 hours.



Interactive Plot

Total time on test — trend at a glance

- ① constant rate (diagonal).
- ② scaled TTT: the nine repairs, close to the diagonal - no trend.

MCF LIFE TABLE (THIS WORKSHEET — 3 MACHINES, 9 EVENTS)

1 ΔMCF = 1/(machines still observed at that age); variance is the naive Poisson form Σ d/r² with normal bounds (convention stated, single-machine identity: MCF = its cumulative count).

2 Age	3 Machine	4 At risk	5 ΔMCF	6 MCF	7 SE	8 95% bounds
90	M2	3	0.3333	0.3333	0.3333	[0.0000, 0.9867]
120	M1	3	0.3333	0.6667	0.4714	[0.0000, 1.5906]
200	M3	3	0.3333	1.0000	0.5774	[0.0000, 2.1316]
340	M1	3	0.3333	1.3333	0.6667	[0.0267, 2.6400]
380	M3	3	0.3333	1.6667	0.7454	[0.2058, 3.1275]
450	M2	3	0.3333	2.0000	0.8165	[0.3997, 3.6003]
560	M3	2	0.5000	2.5000	0.9574	[0.6235, 4.3765]
610	M1	2	0.5000	3.0000	1.0801	[0.8830, 5.1170]
720	M3	2	0.5000	3.5000	1.1902	[1.1672, 5.8328]

MCF life table (this worksheet — 3 machines, 9 events)

- ① ΔMCF = 1/(machines still observed at that age); variance is the naive Poisson form Σ d/r² with normal bounds (convention stated, single-machine identity: MCF = its cumulative count).
- ② to ⑧ The columns Age, Machine, At risk, ΔMCF, MCF, SE, 95% bounds: nine rows. At risk falls from 3 to 2 after M2's end at 500, so each later repair adds 0.5000.

PER-MACHINE FITS + COMMON-B VERDICT (THIS WORKSHEET — 3 MACHINES, 9 EVENTS)

1 Common-β likelihood ratio = 0.1338 (χ^2, 2 dof) → p = 0.9353: one fleet — pooling is defensible.

2 Machine	3 Events	4 Observed to	5 β (own fit)
6 M1	3	800	0.9921
7 M2	2	500	1.0988
8 M3	4	900	1.3055

Per-machine fits + common-β verdict (this worksheet — 3 machines, 9 events)

- ① Common-β likelihood ratio = 0.1338 (χ^2, 2 dof) → p = 0.9353: one fleet — pooling is defensible.
- ② to ⑤ The columns Machine, Events, Observed to, β (own fit).
- ⑥ M1: 3 events, observed to 800, β 0.9921.
- ⑦ M2: 2 events, observed to 500, β 1.0988.
- ⑧ M3: 4 events, observed to 900, β 1.3055.

OVERHAUL OPTIMIZATION (FLEET FIT)

1 C(T) = (Cp + Cf·λT^β)/T with Cp = 4,000, Cf = 25,000; exact minimum T* = [Cp/(Cf·λ(β−1))]^(1/β). Valid while the fleet keeps wearing (β > 1).

	Value
2 T* — optimal overhaul age	319.1
3 Cost rate at T*	103.31 /hr
4 Cost rate running to the observed age	109.19 /hr
5 Saving per machine	5.88 /hr = 51,529 /yr at 8760 h/yr

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- ⑤ Saving per machine 5.88 /hr = 51,529 /yr at 8760 h/yr.

NEXT STEP — RENEWAL PATH (FLEET FIT)

1 The growth test keeps β = 1: repairs are neither bunching nor spacing. The defensible next step is a Weibull analysis of the INTER-ARRIVAL GAPS (Time Dependence ▸ Weibull 2P) — that treats each repair as a renewal, an assumption this verdict just made explicit.

Next step — renewal path (fleet fit)

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The report's foot

- ① The licence line Licensed to ReliaEn Training · RL-2026-0017: the licence the report was made under.

Part 5 — How to interpret the results

How many repairs per compressor. Up to 450 hours all three compressors are watched, so each repair adds one third to the MCF. After 500 hours M2 has left the count, so each later repair adds one half, and by 720 hours the fleet has had 3.5 repairs per compressor. A short record does not pull the average down.

Do the compressors wear? The pooled β is 1.1381, just above 1, but its bounds, 0.5204 to 1.9933, contain 1 and the growth test gives p = 0.789: the data cannot tell this fleet from a stable one. The time between repairs is 209.7 hours now and 238.7 hours on average.

One fleet or three? The compressors' own β values, 0.9921, 1.0988 and 1.3055, differ less than chance allows: the common-β test gives p = 0.9353, so the pooled β describes every machine.

Does an overhaul age pay? With the costs entered, the cheapest overhaul age is 319.1 hours at 103.31 per hour, against 109.19 per hour running to the observed age - a saving of 5.88 per hour, 51,529 a year per compressor at 8,760 hours. The saving rests on a β that may really be 1: collect more history before committing to an overhaul programme. Until then the renewal path the report names - a Weibull fit of the gaps between repairs - is the defensible next step.