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An Ontology-based Cost Modelling Approach for High-Value Manufacturing

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www.cranfield.ac.uk

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Background

Lack of complete and reliable historical data

High level of uncertainties

Complexity in high-value equipment, their service, MRO process, cost elements, etc.

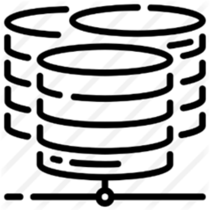
Process

1. MRO trigger event
2. Logbook
3. Technical review panels
4. Work scope
5. Database (Maximo, SAP, etc.)
6. MRO item arrival e.g. Engine arrival
7. Engine strip, clean
8. Inspection (report)
9. Sentencing
10. Order spare/components
11. Review
12. Testing
13. Update database
14. Assembly
15. Back to operation

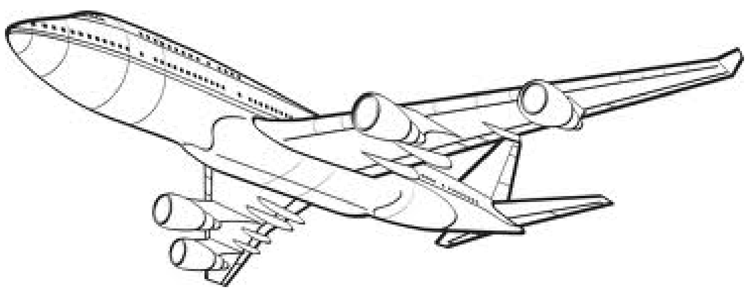
Document

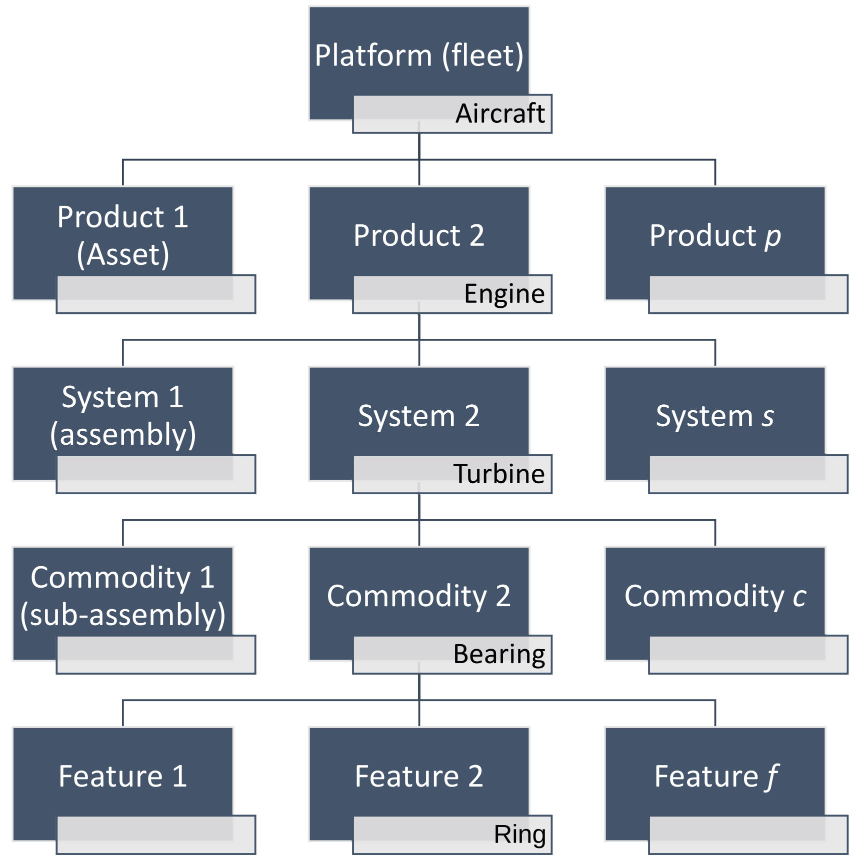
1. Engine rejection report
2. Root-cause analysis
3. Disruption drivers
4. Pareto analysis
5. MRO planning
6. Inventory
7. Logistics
8. Weibull analysis
9. FMEA
10. FMECA
11. RCM

Database

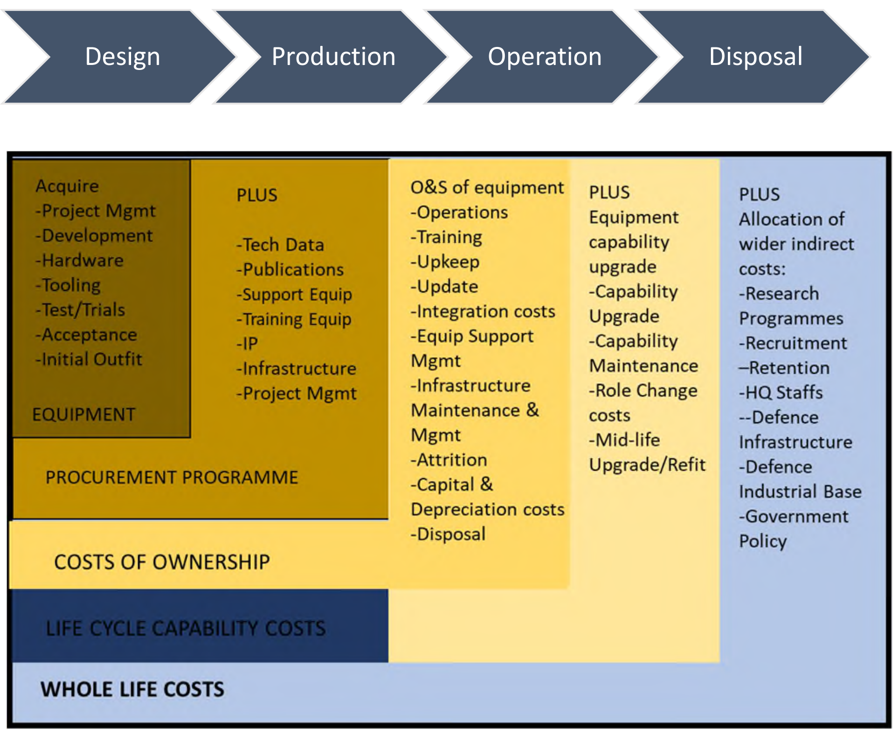


What is the item?





How much does it cost?

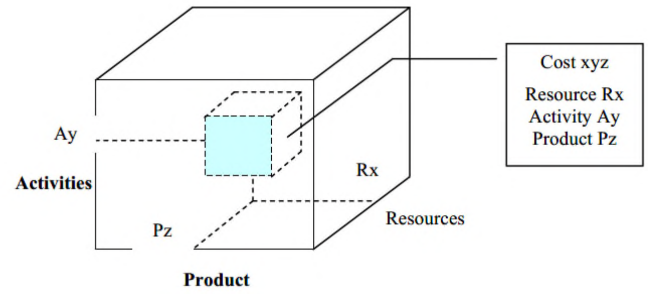


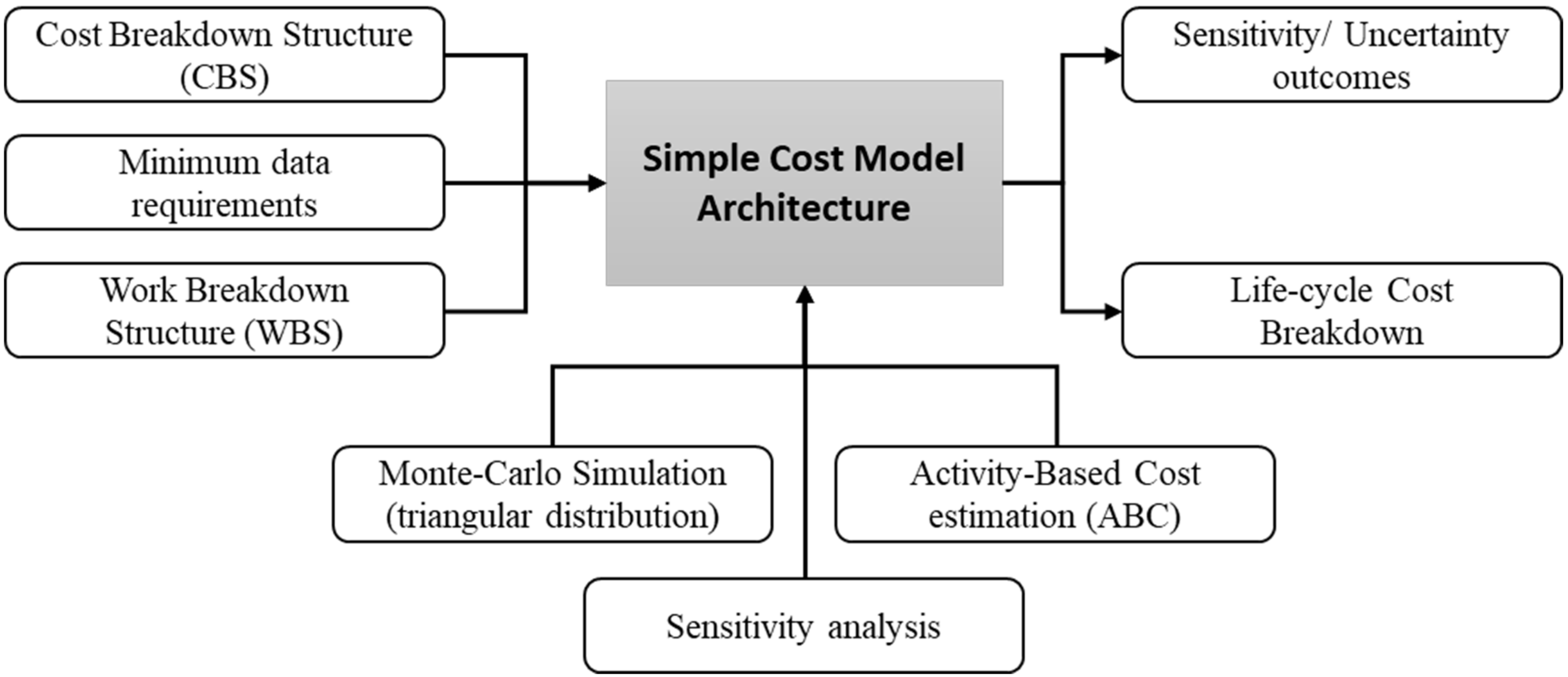
Source: TREATY, N.A., NATO- Cost Structure and Life Cycle Costs for Military Systems.

Product life-cycle cost (LCC)

In the context of business operations, the top-level life-cycle cost breakdown includes the cost of capital expenditure (CapEx) and operating expenditure expenses (OpEx).

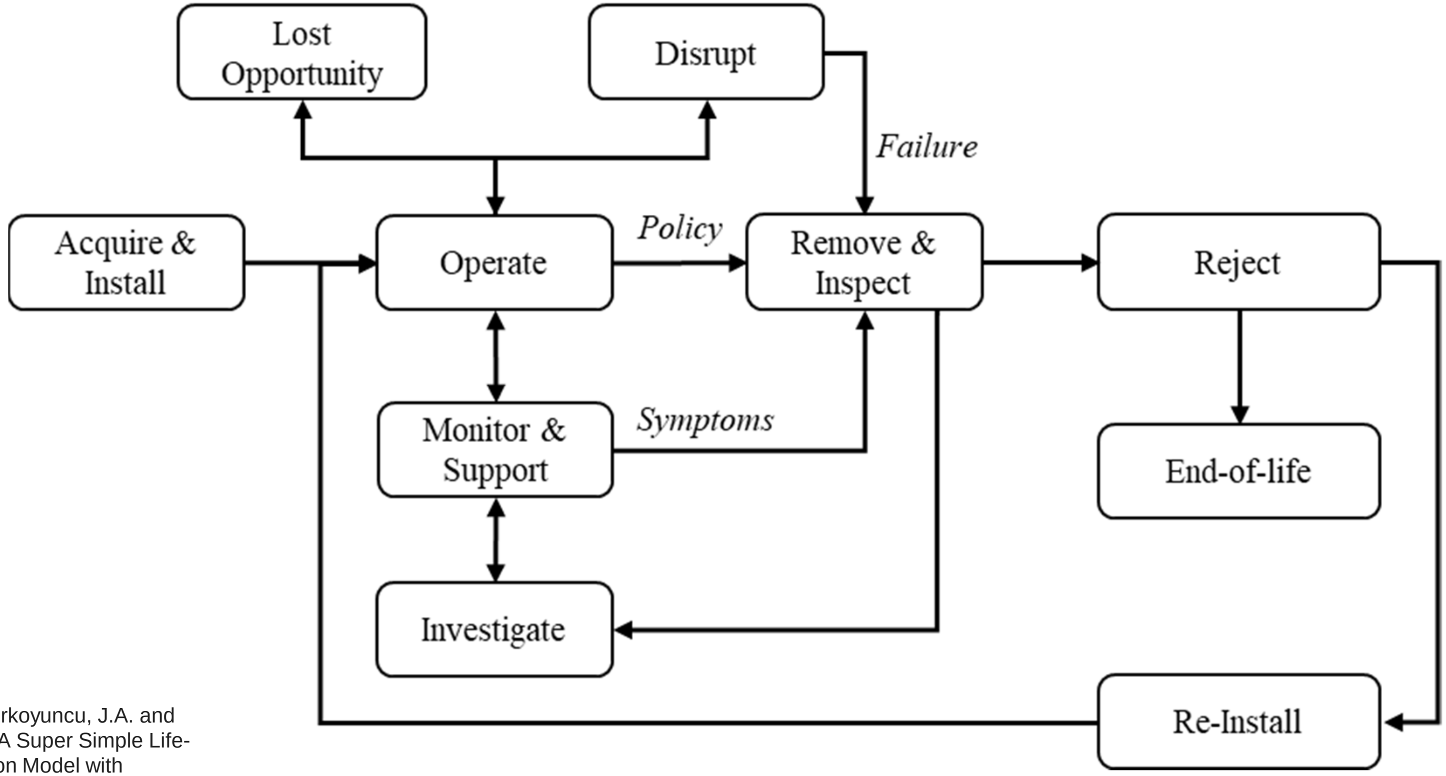
the sum of the estimated costs in the span of acquire to disposal phases of a product or a major asset/equipment (i.e. parent) and all the sub-assemblies (i.e. child).





Source: Farsi, M., Erkoyuncu, J.A. and Harrison, A., 2020. A Super Simple Life-cycle Cost Estimation Model with Minimum Data Requirement. *Available at SSRN 3718042*.

Cost Breakdown Structure (CBS)



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Acquire & Install cost of design and production of an asset (e.g. engine) or acquisition of a component (e.g. bearing), including the cost of assembly and installation.

Operate cost event mainly incorporates the direct cost of operation and consumables (e.g. fuel, gas, water, oil).

During operation, ***Lost opportunity*** refers to the revenue loss due to the lack of product utilization, availability and credibility.

Disrupt is the cost of disruption to the product availability due to a failure in the agreed performance level and capability and according to the terms mentioned within the warrantee and guarantee agreement(s).

Monitor & Support covers the cost of installed base maintenance (i.e. oil change) and regular monitoring.

Investigate refers to the cost of all the investigations and mitigations processes through the product life-cycle.

Remove & Inspect is the cost of taking an item out for inspection.

Reject is the cost of repair and replacement.

Re-install is the cost of re-assembly and re-installation of a product after removal.

End-of-life refers to the product disposal cost and/or revenues if the product has a residual value at the end of life.

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Work Breakdown Structure (WBS)

Acquire & Install	Lost opportunity	Disrupt	Operate
-acquire -assembly -testing -transport -install	revenue loss due to lack of: -utilization - availability -credibility	penalties due to the lack of: -performance - capability	-consumables
Investigate	**Monitor & Support**	**Remove & Inspect**	**Reject**
-investigations	-base maintenance - routine monitoring	-de-install -dis-assembly - inspect transport	-repair -replace
Re-install	**End-of-life**		
-re-assembly -testing -re-install -transport	- disposal cost - revenue from disposal - un-installation - dis-assembly - transport		

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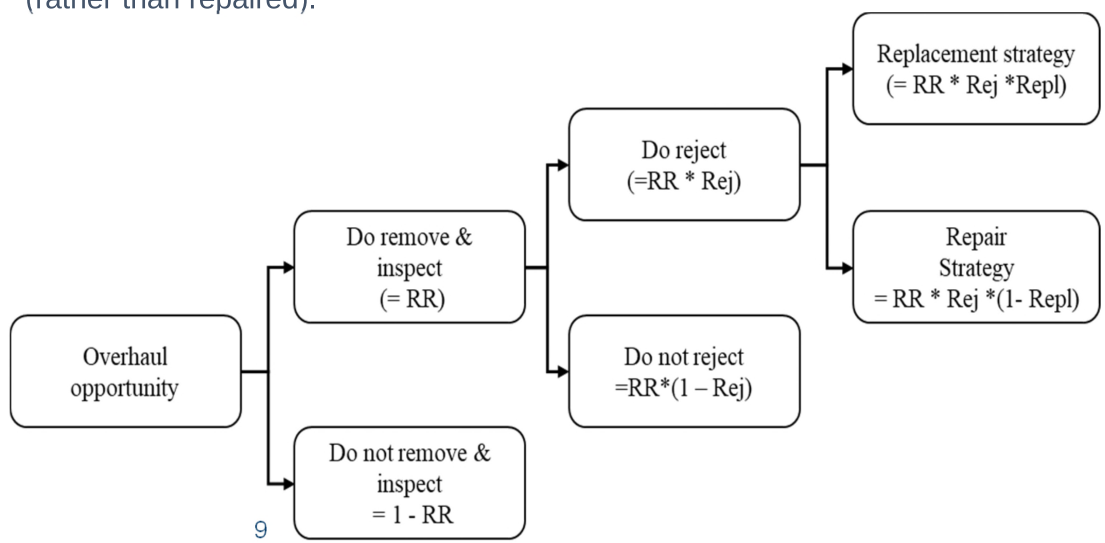
Minimum Data Requirement

- Time Between Overhaul (TBO): is the time between overhaul opportunities for the parent product that contains the child item.
- Removal Rate (RR): is the items' inspection rate at each overhaul opportunity; all individual items may not be inspected every time their parent product is overhauled.
- Overhaul Inspection Interval (OII): is the time between inspections of the child item when the parent product is overhauled; this can be therefore calculated as OII=TBO/RR.
- Rejection rate (Rej): is the probability that the inspected item is rejected (i.e. cannot be used without repair or replacement).
- Replace rate (Repl): is the probability that if an item is rejected, it will be replaced (rather than repaired).



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Frequency of cost events based on minimum requirement:

Cost event	Symbol	Frequency formula (/year)
Remove & Inspect	$f_{R\&I}$	$= 1/OII = RR/TBO$
Re-Install	f_{RI}	$= f_{R\&I}$
Reject	f_{Rej}	$= f_{R\&I} \times Rej$
Replacement strategy	f_{Repl}	$= f_{Rej} \times Repl$
Repair strategy	f_{Rep}	$= f_{Rej} - f_{Repl}$ $= f_{Rej} \times (1 - Repl)$

TBO = Time Between Overhauls

OII = Overhaul Inspection Interval

RR = Removal rate

Rej = Rejection rate

Repl = Replace rate

- ***Frequency of cost events (f)***: Given the parameters above, frequencies of some of the LCC cost events are calculated as:

- ***Unit cost or standard cost of events (£)***: is the unit cost for each cost event (or sum of unit costs of activities at each event) throughout the life-cycle.

Activity-based cost (ABC) estimation is one of the analytical approaches where LCC can be estimated as the sum of the costs of activities associated to the life-cycle.

$$(\text{Subtotal cost})_{e_i} = (\text{Unit cost})_{e_i} \times (\text{Quantity})_{e_i},$$

$$\text{Total cost} = \sum_i (\text{Subtotal cost})_{e_i}.$$

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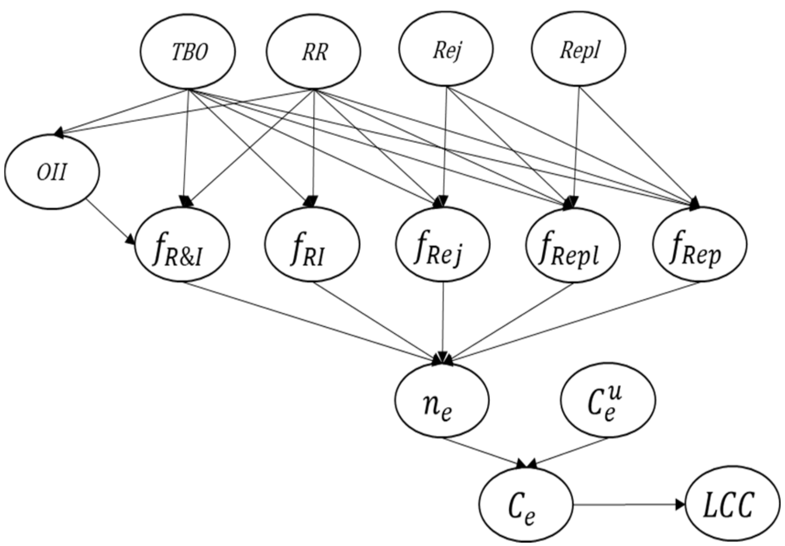
Activity-Base Cost estimation



Total Lifecycle cost (LCC):

- $LCC = \sum_{e=1}^{n} C_e,$
- $C_e = C_e^u \times n_e,$
- $C_e^u = \sum_{a=1}^{m_e} C_{e,a}^u,$
- $n_e = f_e \times T,$

- C_e: Cost of event *e*
- C_e^u: Unit cost of event *e*
- n_e: Number of event *e*
- $C_{e,a}^u$: Unit cost of activities for event *e*
- T: *Lifecycle of a product*

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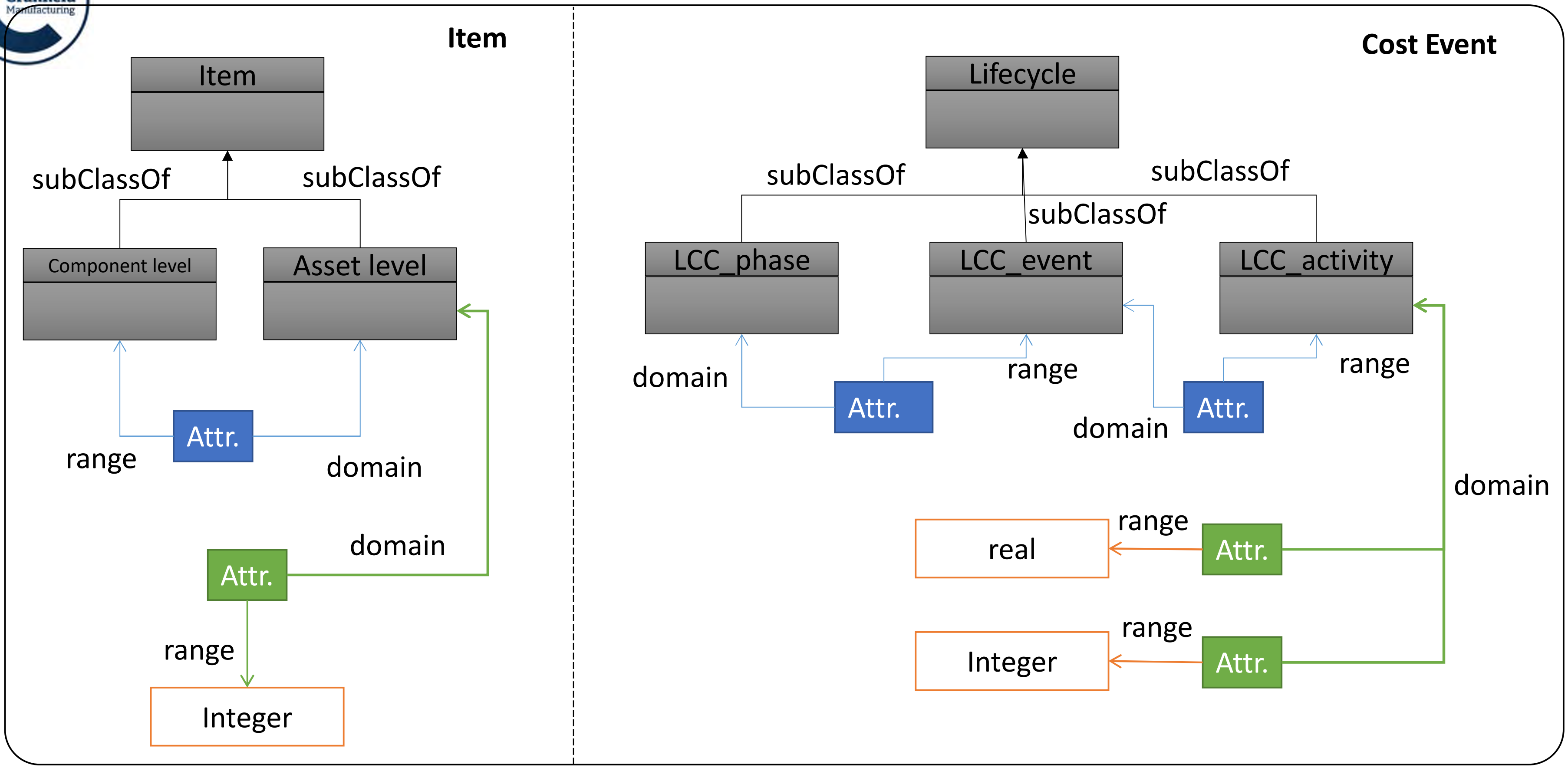
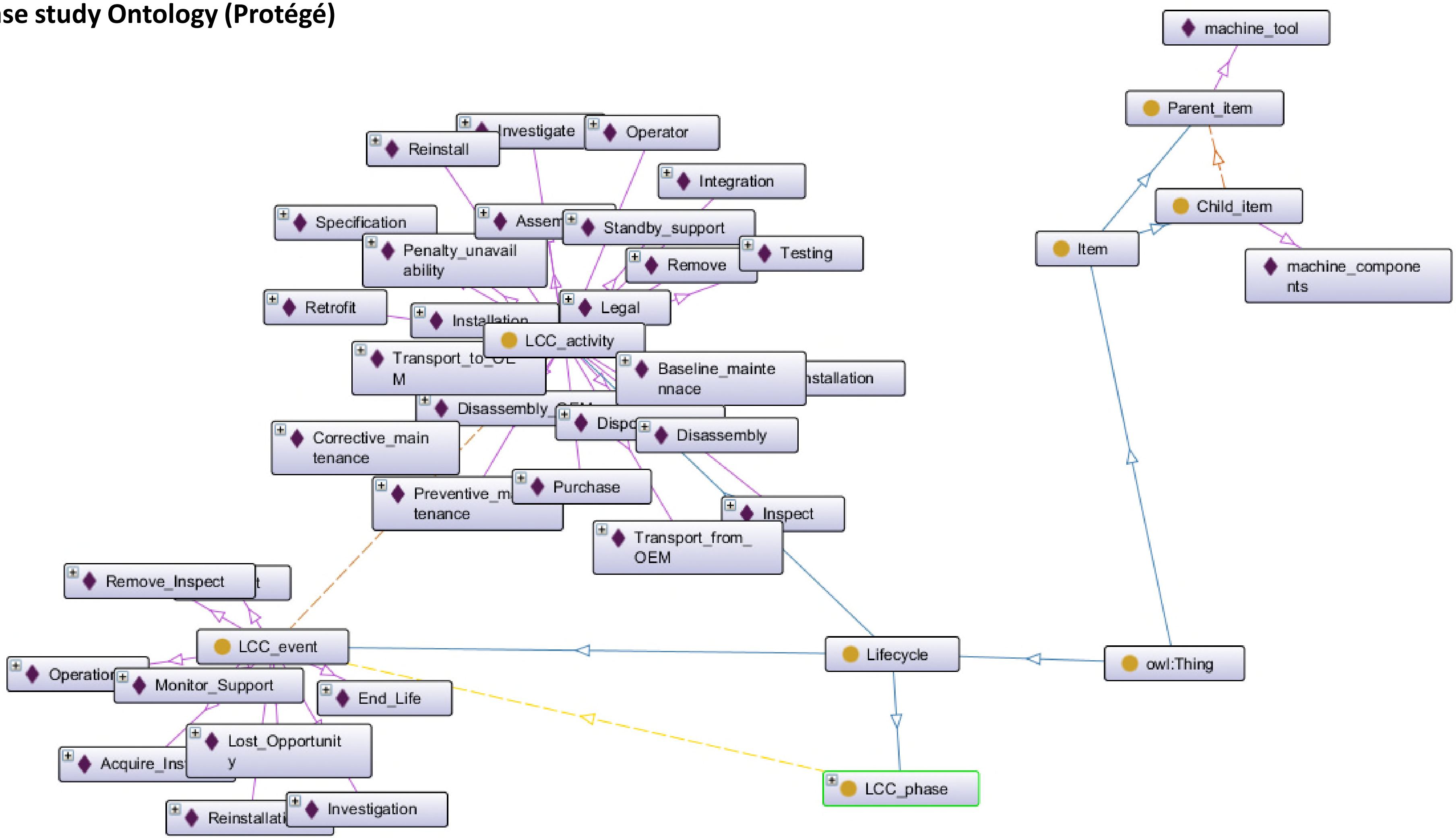


Case study Ontology (Protégé)



Case Study CBS/WBS

Life-cycle cost phases	Cost activities	Unit cost (£K)	Frequency (/year)
Acquire & Install	Purchase price	£348.00	1/30
	Legal fee	£1.60	1/30
	Dis-assembly	£2.00	1/30
	Transport	£2.00	1/30
	Assembly	£16.00	1/30
	Specification	£4.00	1/30
	Installation	£0.80	1/30
	Testing	£16.00	1/30
	Integration	£16.00	1/30
Lost Opportunity	Penalty	£0.55	1.00
Operate	Operator	£1.35	1/30
Investigation	Investigation	£1.50	2.00
Monitor & Support	Baseline maintenance	£3.75	1.00
	Standby support	£0.50	12.00
Remove & Inspect	Remove and Inspect	£0.48	12.00
Reject	Preventive maintenance	£1.19	2.00
	Corrective maintenance	£0.71	10.00
	Spare part disposal	£5.00	6.00
	Spare part	£15.00	6.00
Re-Install	Re-install	£0.48	12.00
End-of-life	Uninstallation	£2.50	1/30
	Dis-assembly	£2.50	1/30
	Transport	£0.50	1/30
	Retrofit	£50.00	1/30

Minimum Data Requirement

Parameter	TBO (years)	RR	OII (years)	Rej	$Repl$
Value	0.1	1	0.1	1	0.5

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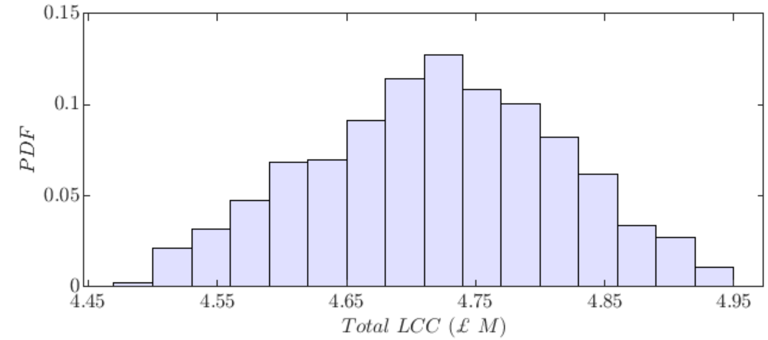
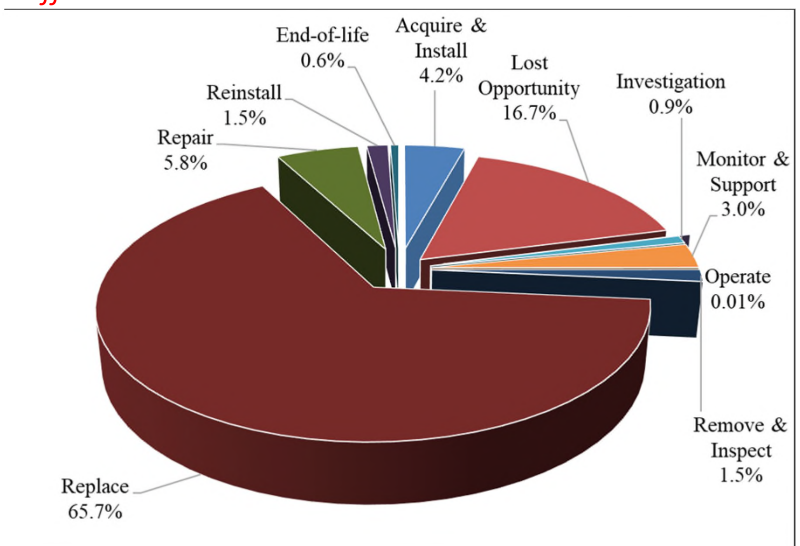
Case Study

Sensitivity and Uncertainty Analysis

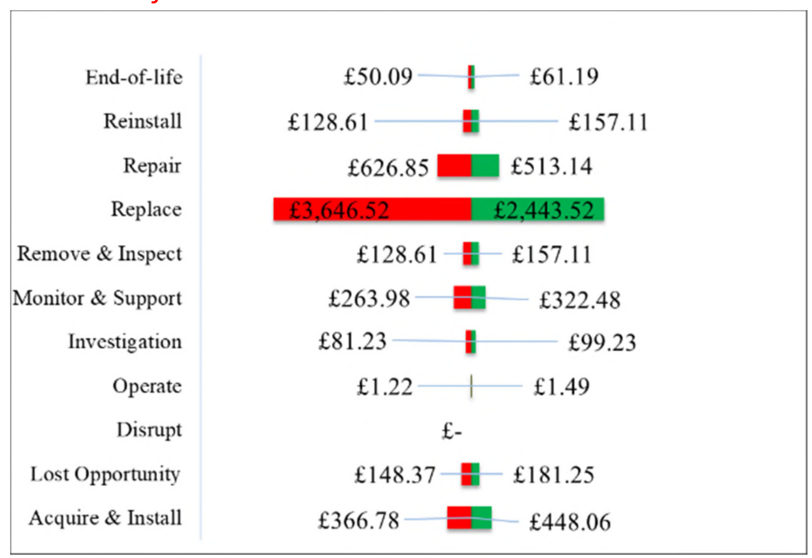
Following the application of three-point-estimation, the results show a triangular distribution as expected



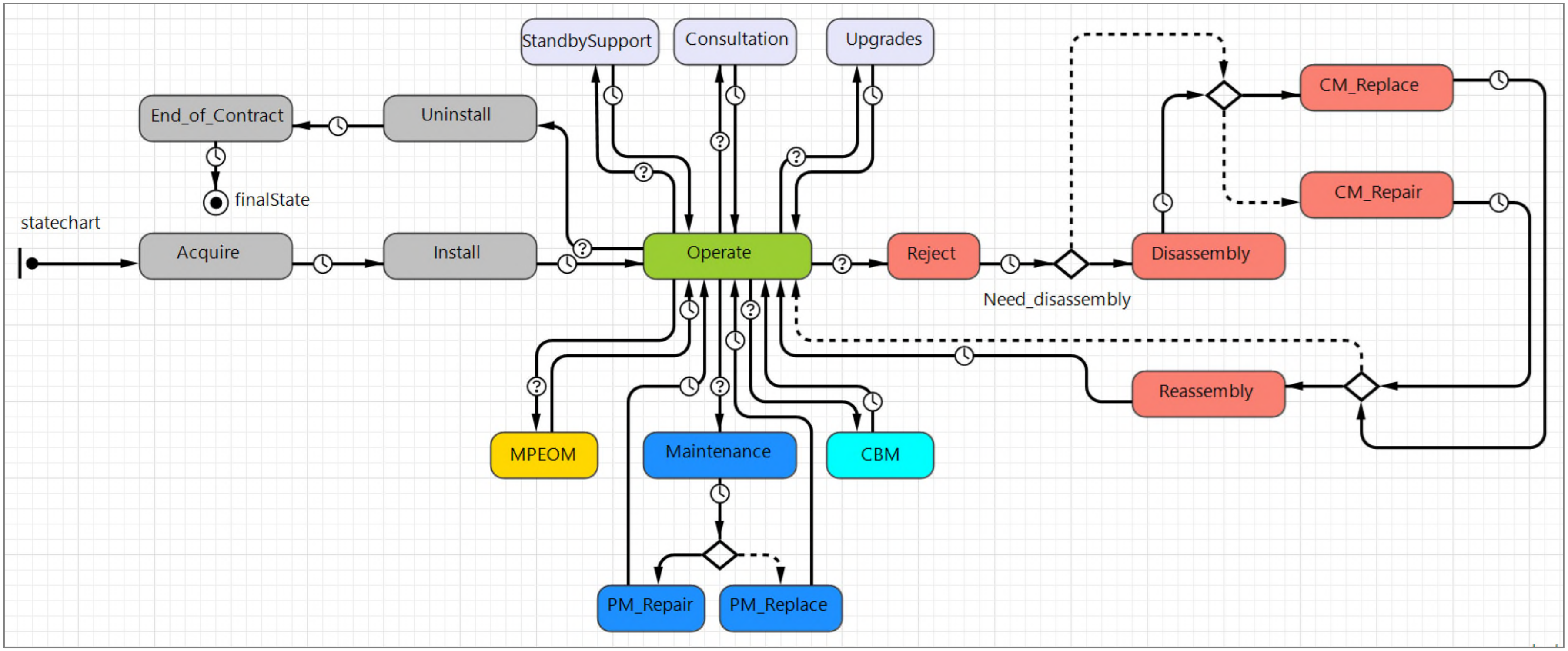
The relative impact of the ±5% sensitivity variation on different LCC events



A deterministic sensitivity analysis with the sensitivity variation of ±5%

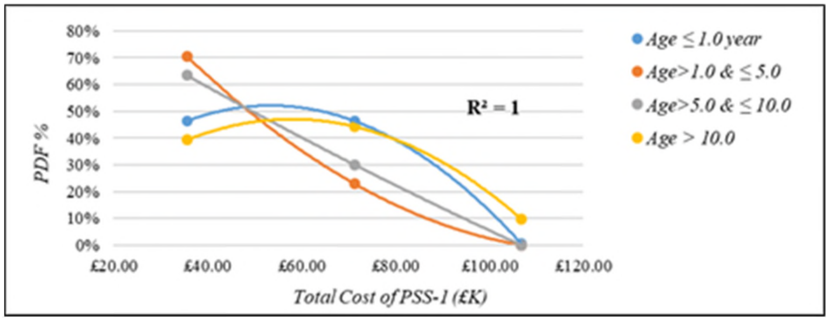


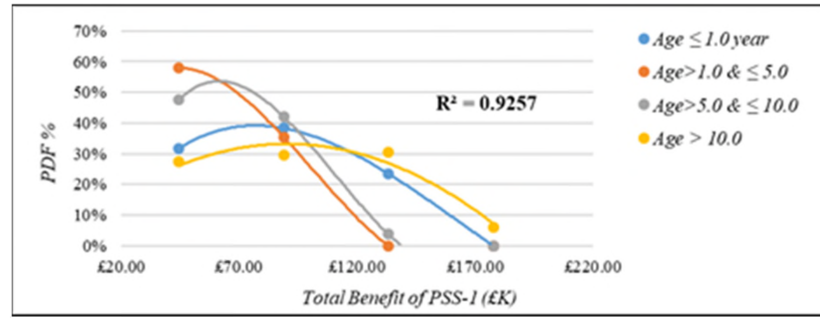
APPLICATION: AGENT-BASED MODEL OF FLEXIBLE CUSTOMIZATION FOR SERVITIZATION

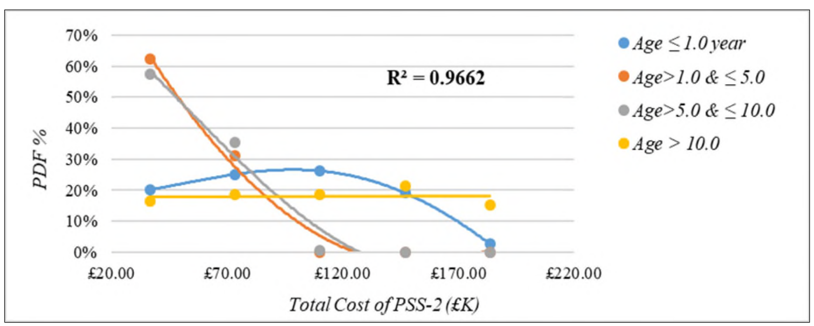


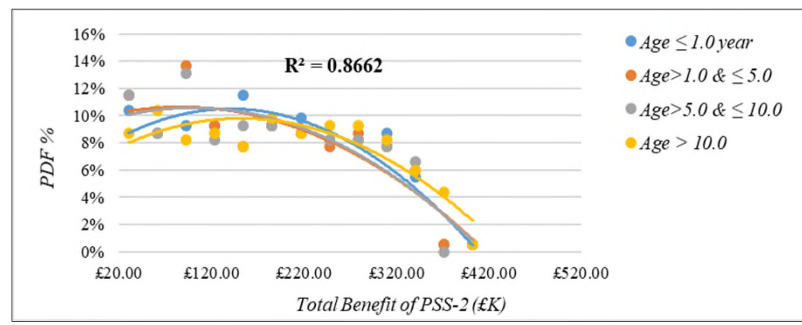
Source: Farsi, M., Erkoyuncu, JA. (2020). An Agent-based Model for Flexible Customization in Product-Service Systems, Procedia CIRP

SERVICE CONTRACT PRICE









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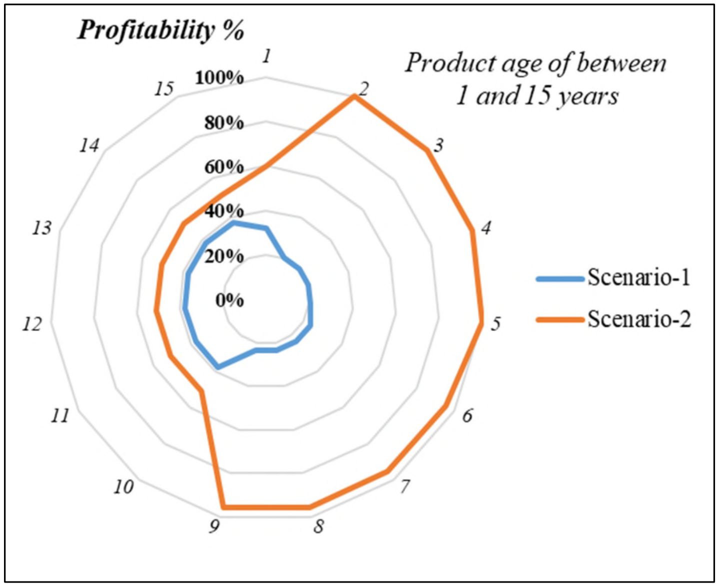
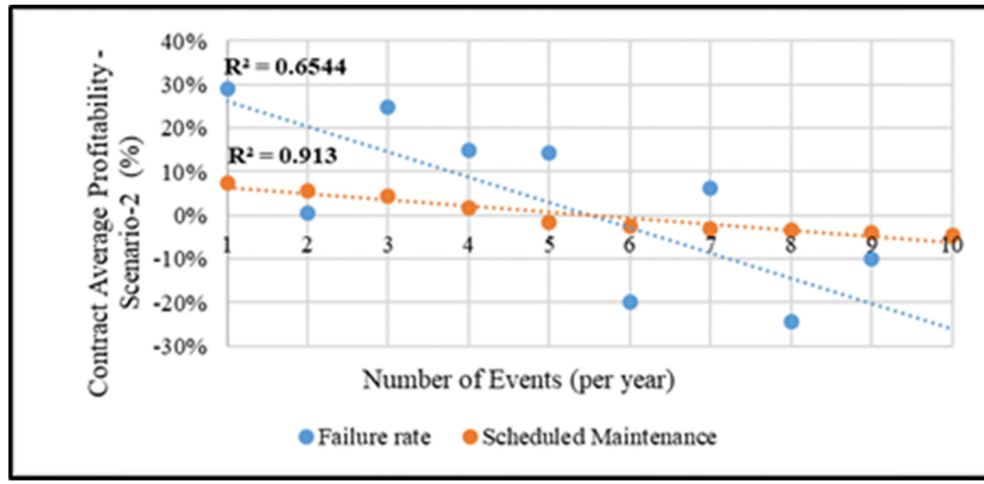
AVERAGE PROFITABILITY



- 1 – Spare-part contract
- 2 – Availability-based contract



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Thank you
Any Question?

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