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Life Cycle Cost (LCC) Analysis

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Why LCC analysis?

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INCREASED RESPONSIBILITY IN PSS = INCREASE NEED TO CONTROL LCC!

More about: Discover › Sustainability › Global ›

A circular business model

Our long-term service agreements retain product stewardship. This provides a means to close the loop on material usage – reducing waste, increasing efficiency, and enhancing the robustness of our supply chain.

Rolls-Royce takes TotalCare digital with Microsoft and Singapore Airlines

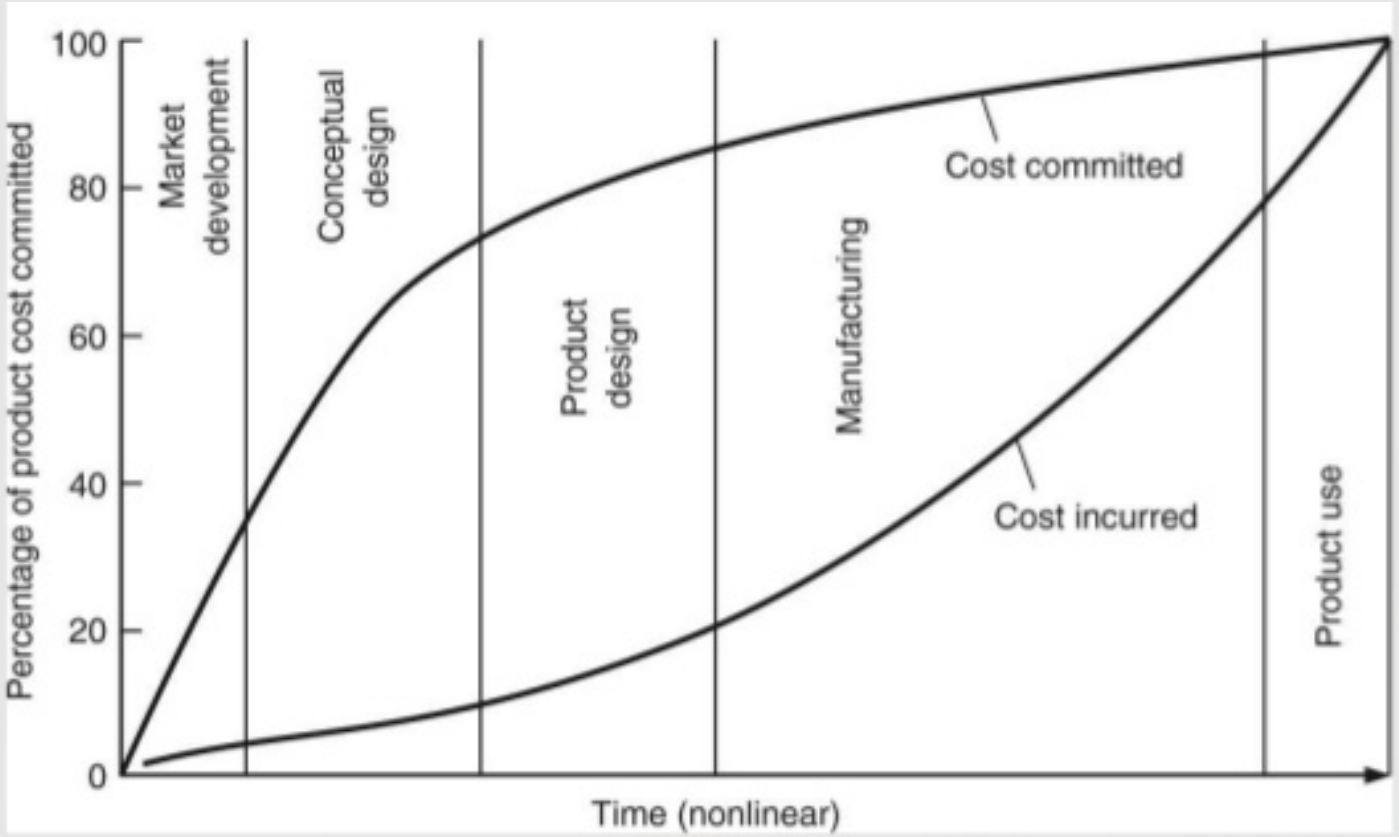
Monday, 11 July 2016

Rolls-Royce and Microsoft Corp. are collaborating to harness the power of digital technology to transform the aerospace industry.

This collaboration brings together best-in-class solutions for aerospace engineering and cloud computing, including advanced analytics and the Internet of Things (IoT), to fundamentally change engine-related operations and services. This capability will be incorporated into Rolls-Royce's industry-leading TotalCare® services to significantly reduce cost, improve on-time performance and provide better value to our customers and the industry as a whole.

Built on the Microsoft Azure cloud platform and utilising Microsoft's Azure IoT Suite to collect and aggregate data from disparate, geographically distributed sources and Cortana Intelligence Suite to uncover data insights, the new digital capability is able to manage and integrate much broader quantities of airline operational data.

Why LCC analysis?



Adapted from D. Ullman, *The Mechanical Design Process*, 4th ed., McGraw-Hill, New York,2010.

80% of LCC are committed in the design phases

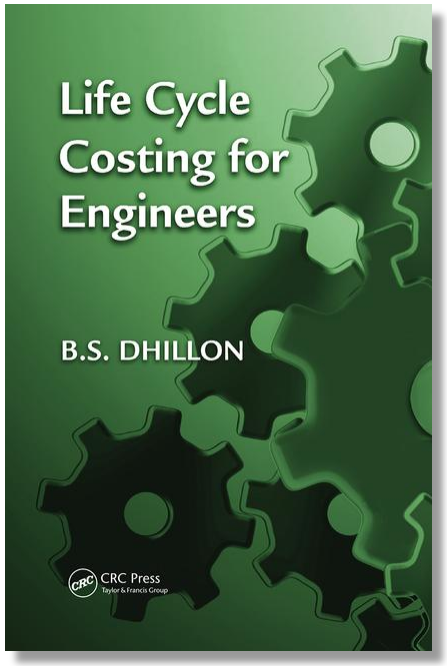
About LCC and LCC analysis

Life Cycle Costs are the total cost associated with the acquisition and ownership of a product or system over its full life.

The primary objective of a LCC analysis is to evaluate and/or optimize the LCC of a product or service.

Important to remember:

1. LCC outputs are only estimates and accuracy is dependent on the inputs provided;
2. LCC models require a large volume of data which can be difficult and expensive to retrieve;
3. LCC results are not good budgeting tools and are only effective as design comparison/trade-off tools;
4. LCC analysis requires a specific scenario and demands details such as how the model will age with use, how damage will occur, how long the model will survive and how cost processors (labor costs, material costs, parts consumption, maintenance costs) will function for each time period.



Dhillon, B.S., 2009. *Life cycle costing for engineers*. Crc Press.

Cost definitions

Non-recurring and recurring costs

Non-recurring costs refers to one-time costs incurred at some point in the lifecycle of a product/system. These costs are typically for development or investment (i.e. research, design, certification). **Recurring costs are costs which are repeated throughout the lifecycle of the system/product**. These costs usually relate to those which are required for production, consumables, labor and maintenance.

Fixed and variable costs

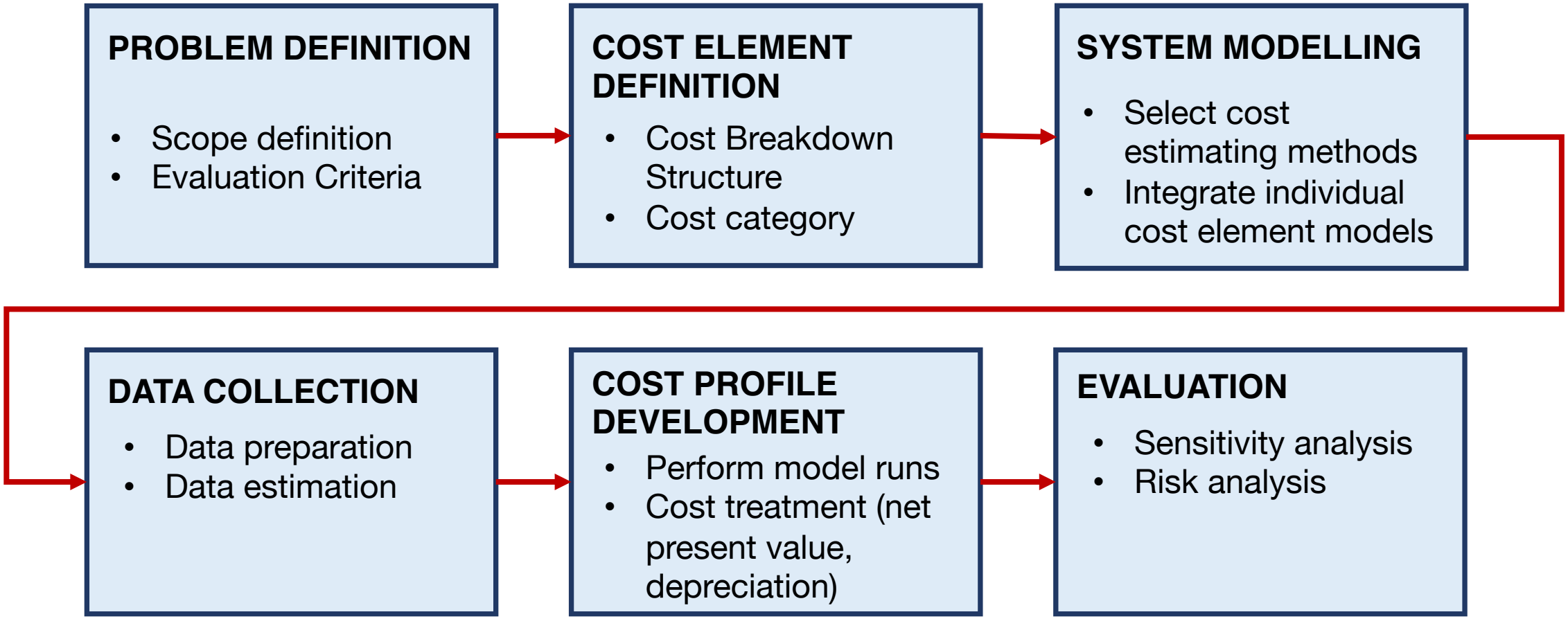
Fixed costs are the costs of production that **do not change when the rate of output is altered** (ex. Investment on CNC machine)

In contrast, **variable costs change with the rate of output**. These costs include elements such as labor, material, and machining.

Direct and indirect costs

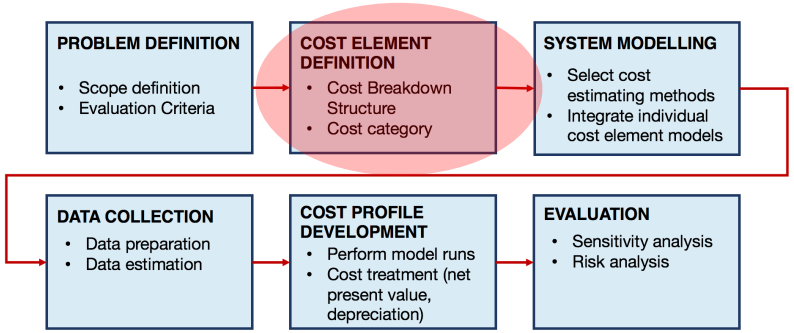
Direct costs can be classified into specific causes, and are thus more easily identified and can be associated with a product or a service. **Indirect costs are the opposite - they are difficult to identify or to be assigned to a specific category. These costs are hence often labelled as overheads.** Examples of indirect costs include cleaning, building works, lighting

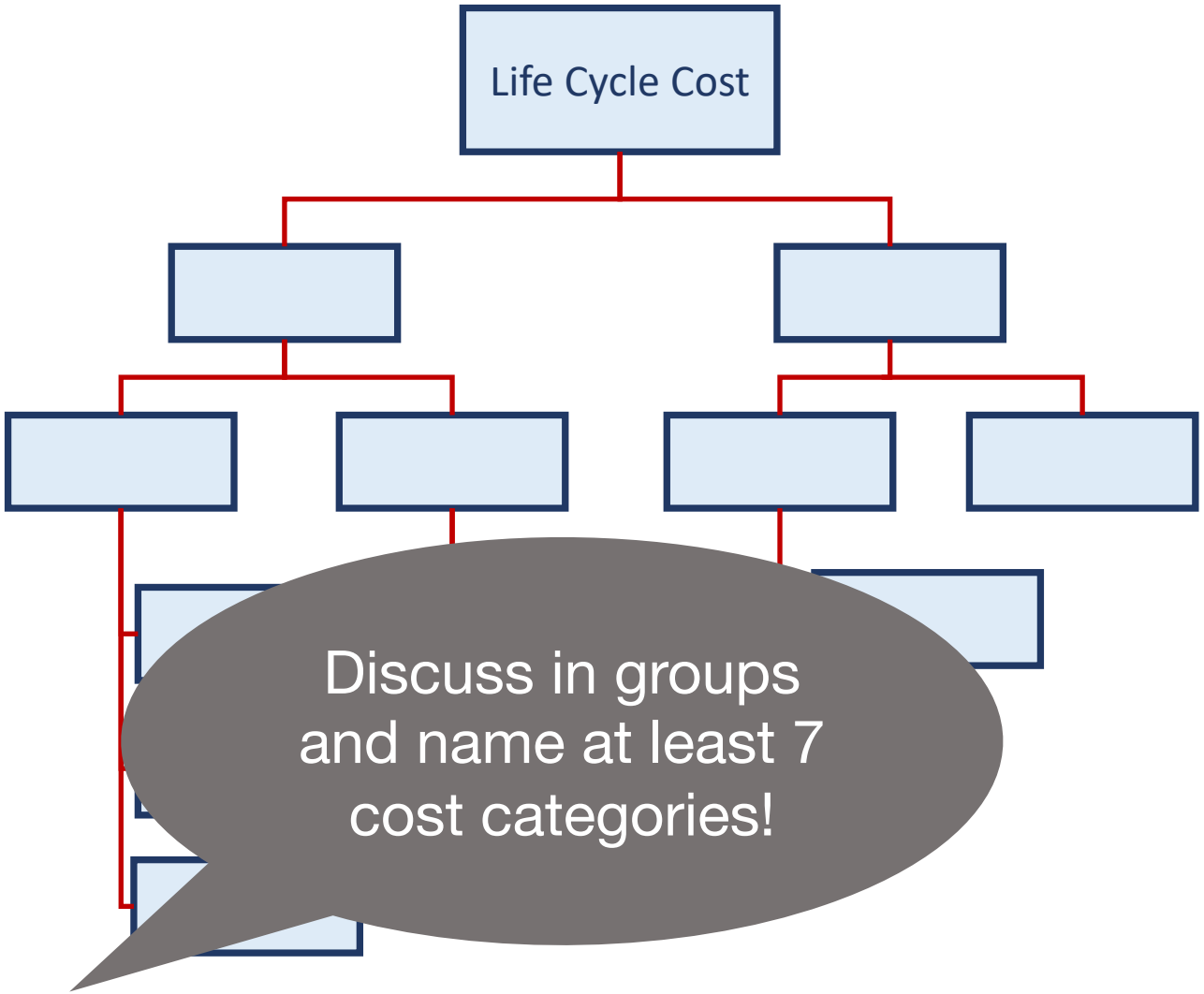
LCC Analysis process



"Reliability of systems, equipment and components ",
British Standards Institution, 5760-23, 1997.

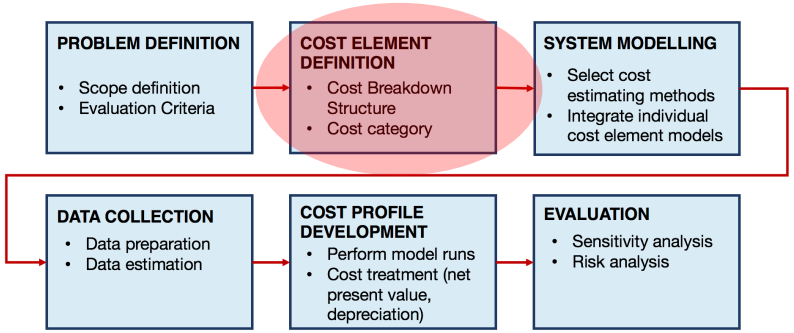
Cost Breakdown Structure

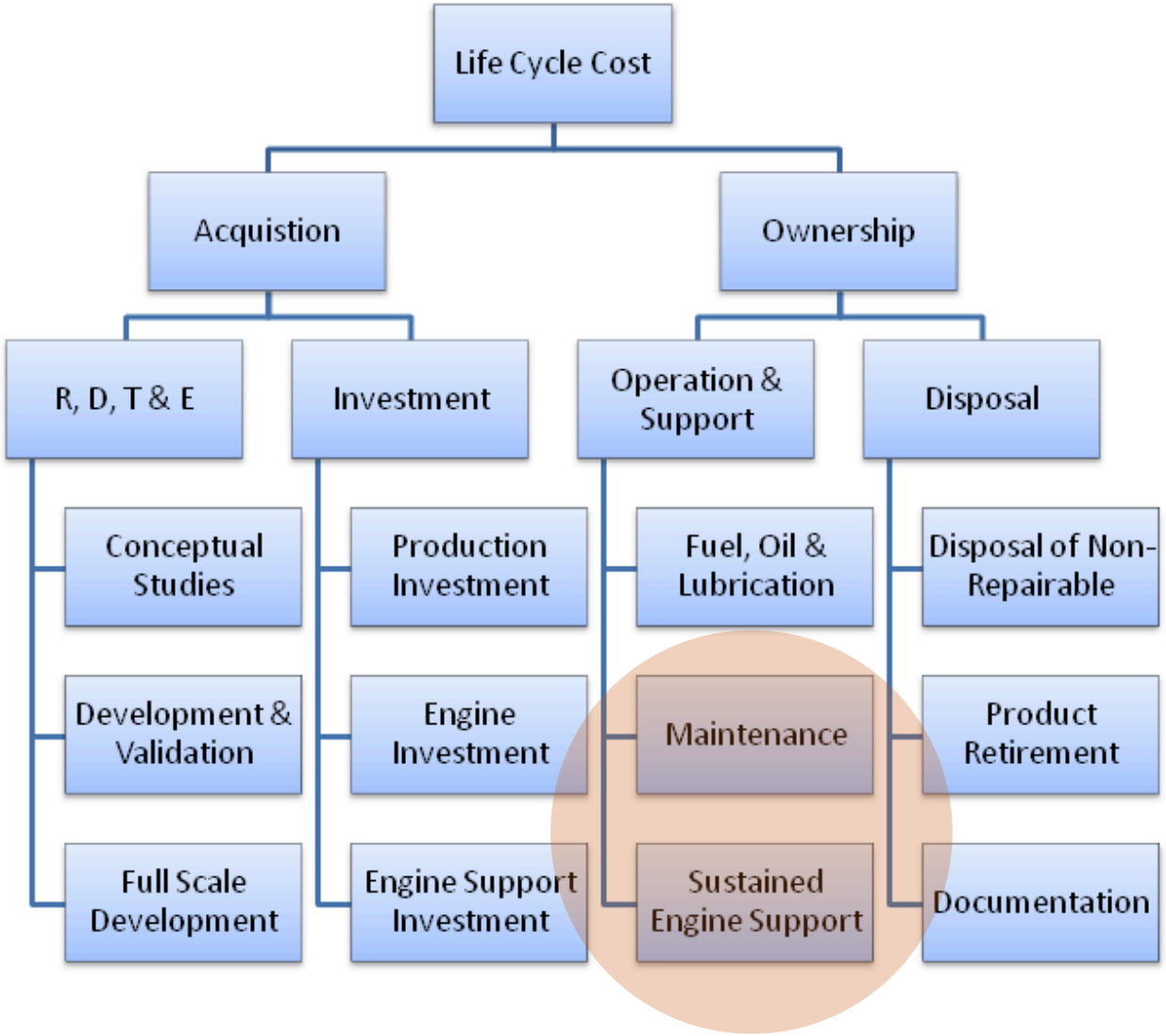




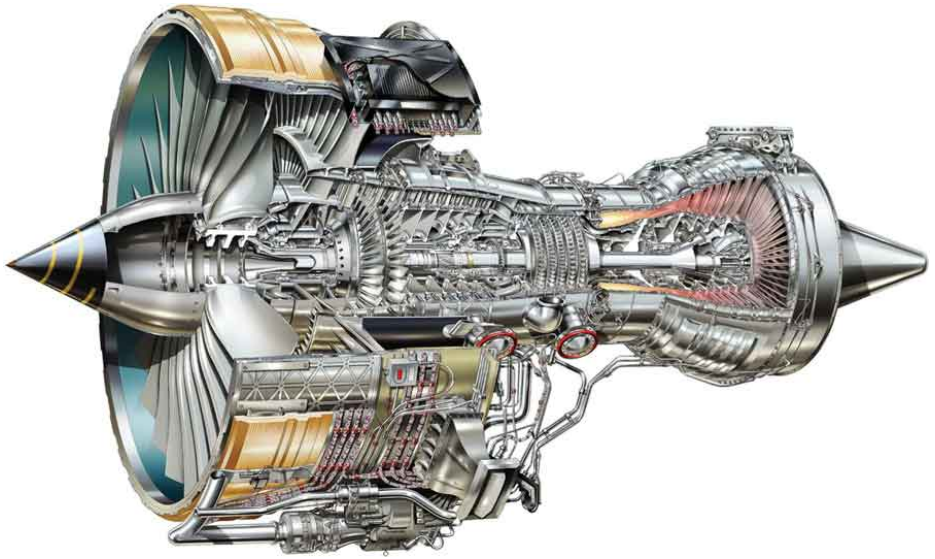
- To estimate total LCC, it is necessary to break LCC down into its various cost elements
- The identification of the cost elements is subjective upon the purpose and scope of the LCC study
- should only include the relevant cost elements and to discard elements which do not greatly influence LCC

Cost Breakdown Structure





Example (Aero-engine)

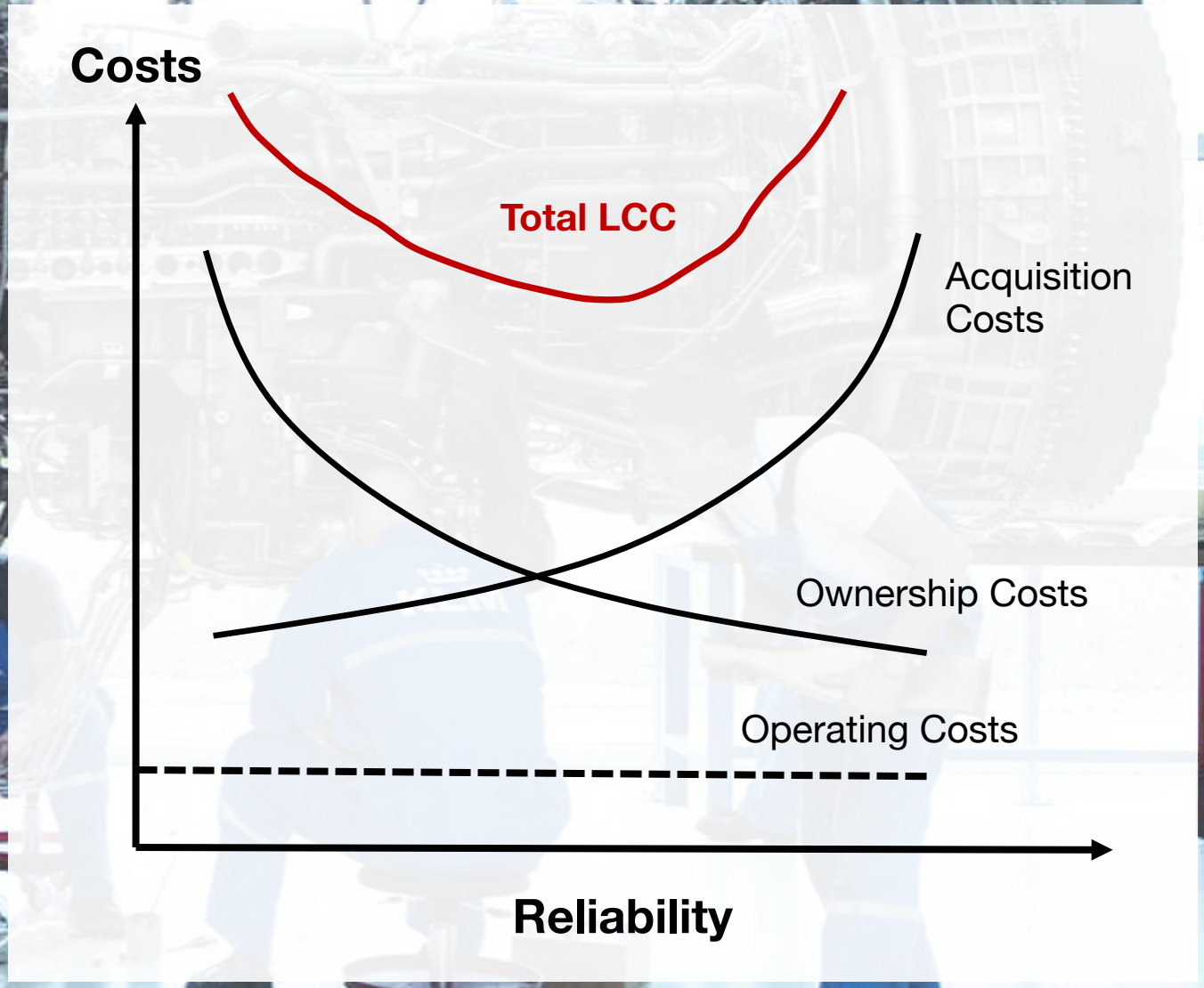


Gibbs, R. E. "Life-cycle cost modelling of military aero-engines in Rolls-Royce," Seminar on Life Cycle Costs. Professional Engineering Publishing Ltd, Heslington, England, 1998, pp. 31-44.

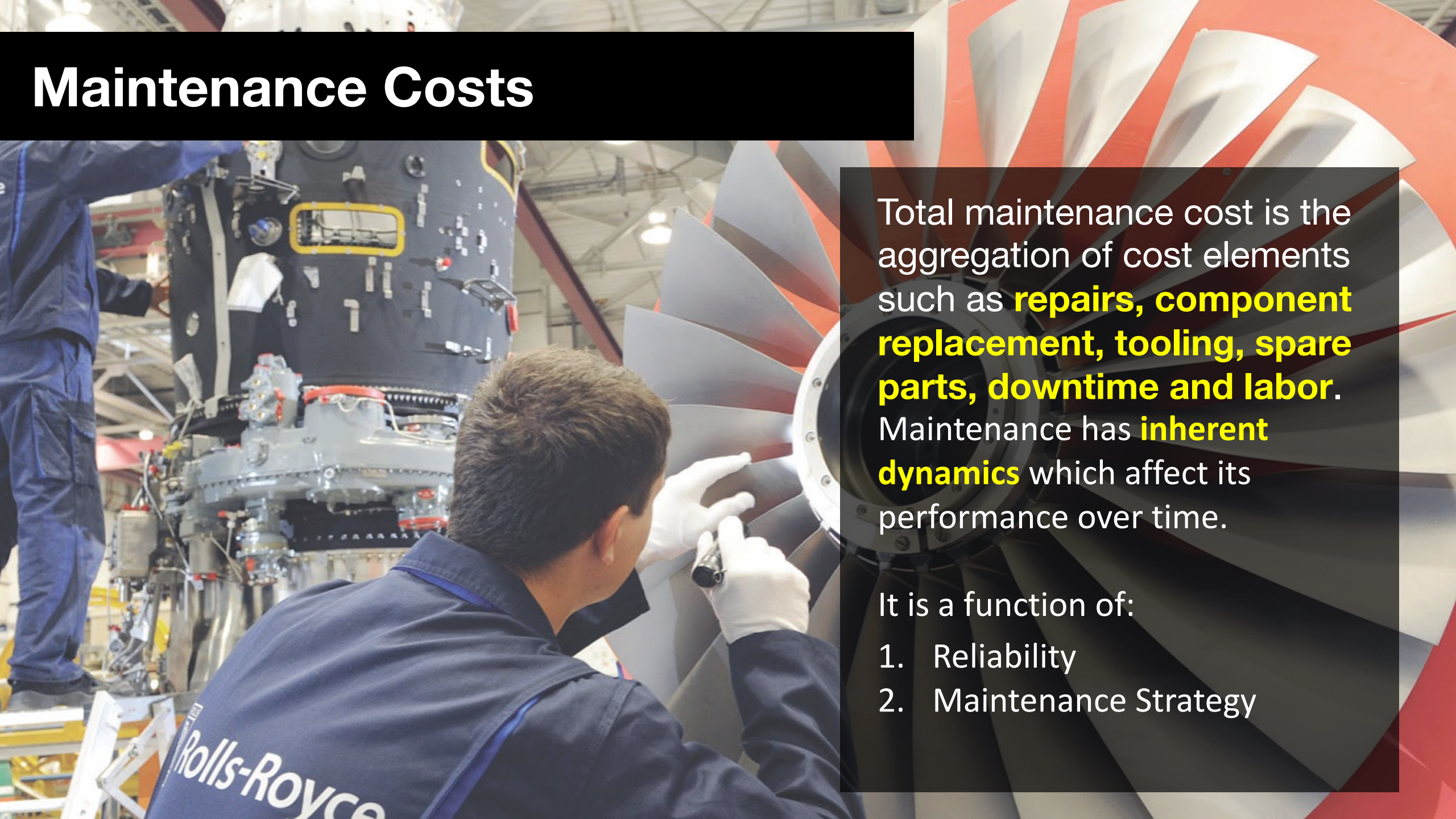
Impact of Maintenance on LCC

Dependability:

Dependability describes the product's **availability influencing factors**, such as reliability, maintainability and maintenance support



Maintenance Costs



Total maintenance cost is the aggregation of cost elements such as **repairs, component replacement, tooling, spare parts, downtime and labor**. Maintenance has **inherent dynamics** which affect its performance over time.

It is a function of:

1. Reliability
2. Maintenance Strategy

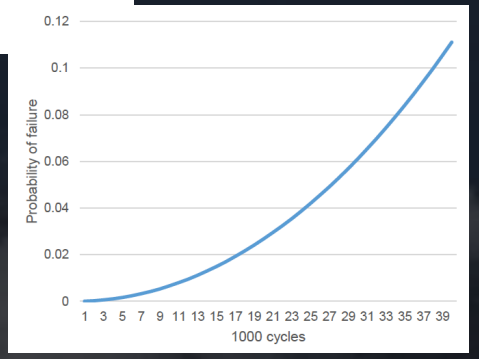
Reliability

Is defined as the probability that a system or component will perform its required functions under stated conditions for a specified period of time

$$p_f = 1 - e^{-(\frac{N}{\lambda})^k}$$

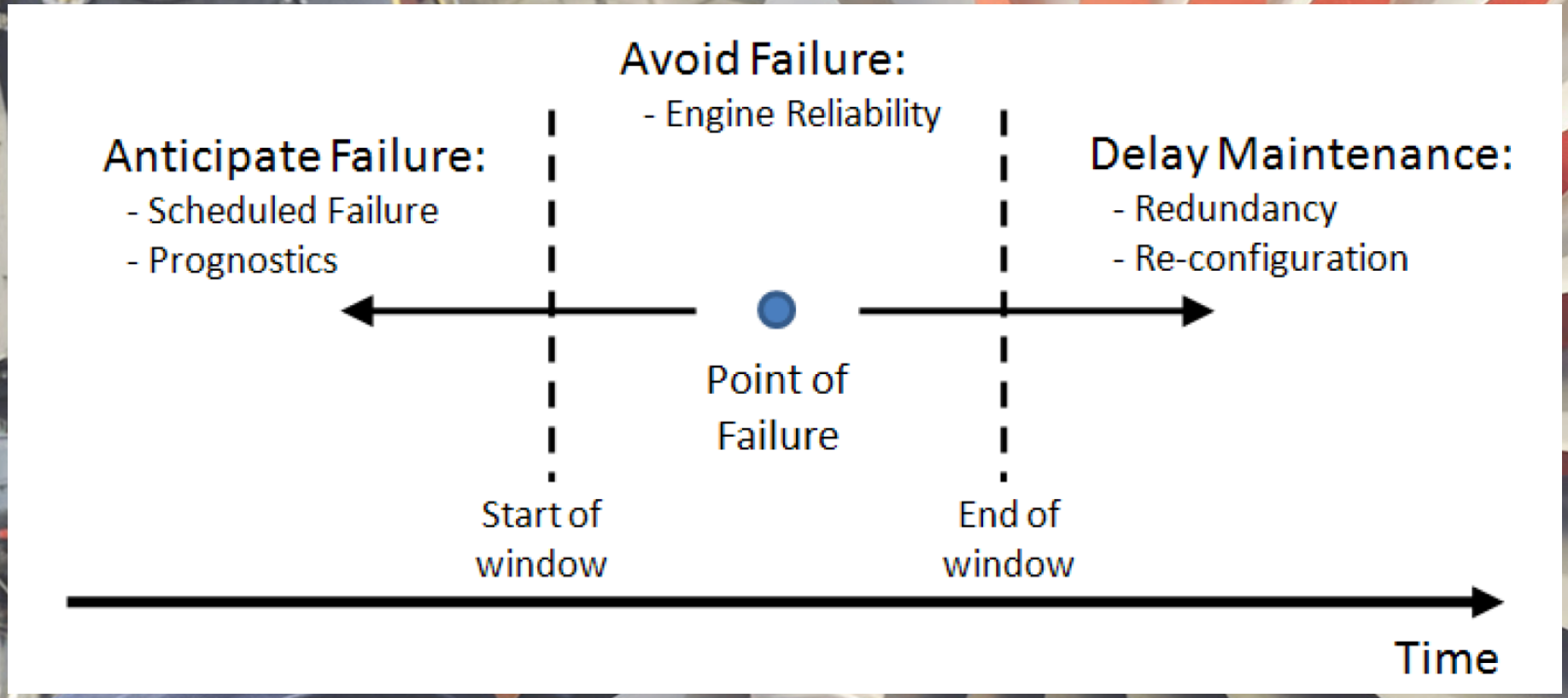
$$\lambda = L * (\ln(0.9))^{-1/k}$$

$$k = 2$$



Usually determined by probability distributions (e.g. Weibull)

Maintenance strategy



Maintaining the window of engine operation is determined by, **The ability of the engine to avoid failure,** The **anticipation of failure and taking appropriate actions during the maintenance period, The delaying of maintenance, following failure, to a subsequent maintenance period.**

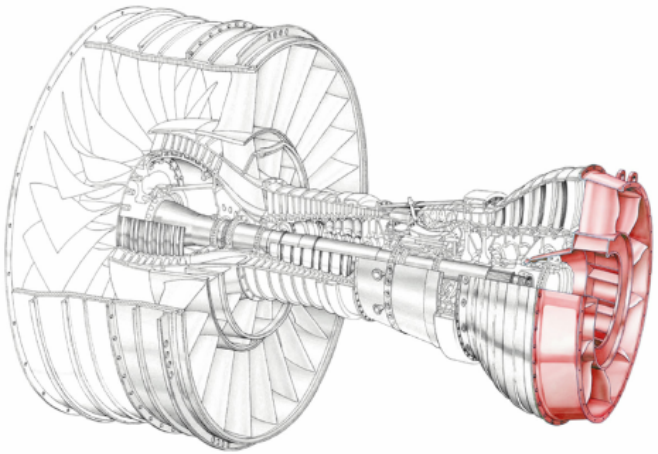
Downtime costs

Period during which an equipment or machine is not functional or cannot work. It may be due to technical failure, machine adjustment, maintenance, or non-availability of inputs such as materials, labor, power. Also called waiting time.

Opportunity costs

The loss of other alternatives when one alternative is chosen

Example LCC Analysis



Turbine Rear Structure (TRS)

PROBLEM DEFINITION
- Scope definition
- Evaluation Criteria

COST ELEMENT DEFINITION
- Cost Breakdown Structure
- Cost category

SYSTEM MODELLING
- Select cost estimating methods
- Integrate individual cost element models

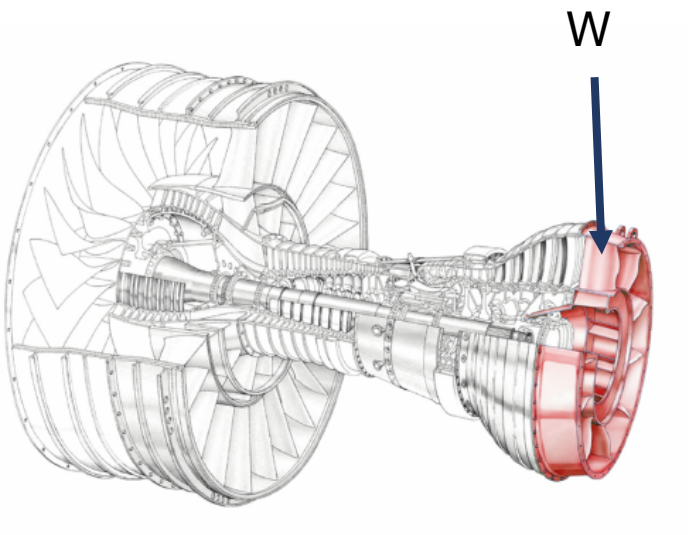
DATA COLLECTION
- Data preparation
- Data estimation

COST PROFILE DEVELOPMENT
- Perform model runs
- Cost treatment (net present value, depreciation)

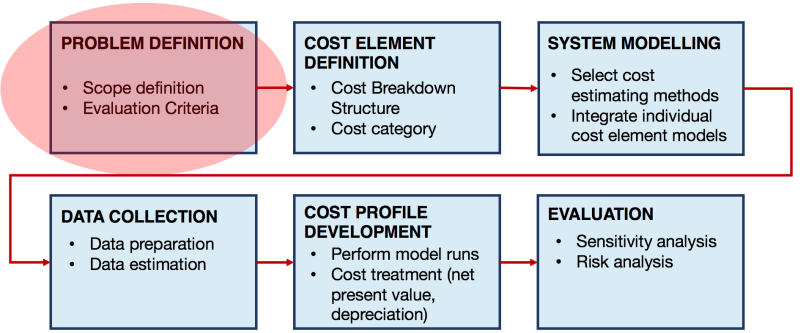
EVALUATION
- Sensitivity analysis
- Risk analysis

Thomsen, B., Kokkolaras, M., Månsson, T. and Isaksson, O., 2017. Quantitative Assessment of the Impact of Alternative Manufacturing Methods on Aeroengine Component Lifing Decisions. *Journal of Mechanical Design*, *139*(2), p.021401.

Problem Definition



N (leads to failure)

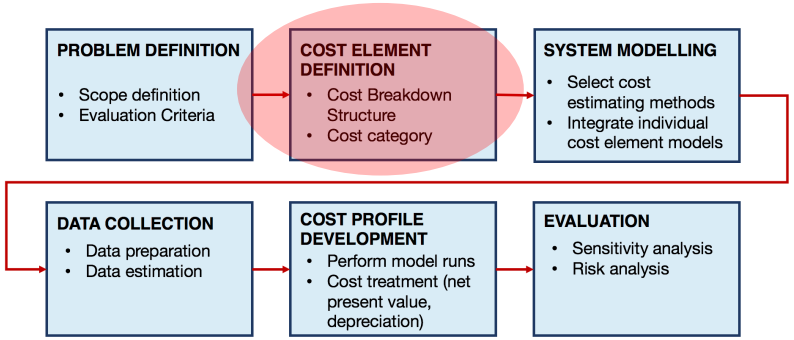


Develop a (scalable) LCC model depending on Weight of the TRS (W) expected Life Cycles (N), and PSS strategy

PSS strategies:

-One part, through life of engine
-Substitute part after part of engine life-time
-One part, repair during life-time
-Multiple parts remanufactured

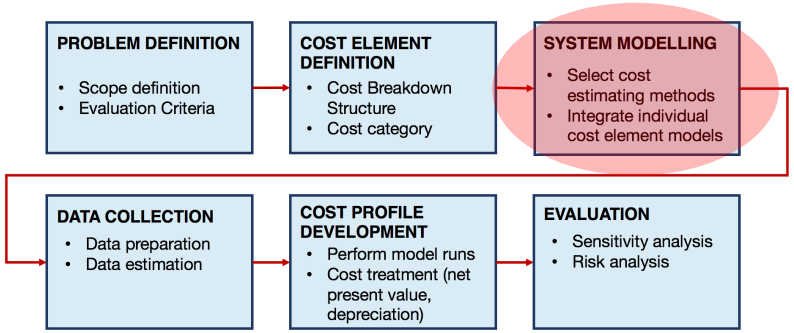
Cost Elements



- Materials
- Manufacturing
- Transportation
- Fuel
- Replacemenht
- Repair
- Inventory
- Disposal
- donwtime cost_repair
- downtime cost replacement
- Remanufacture
- **Total cost**

Identify the cost elements that are relevant for your problem (think about which lifecycle phases are relevant)

System Modeling



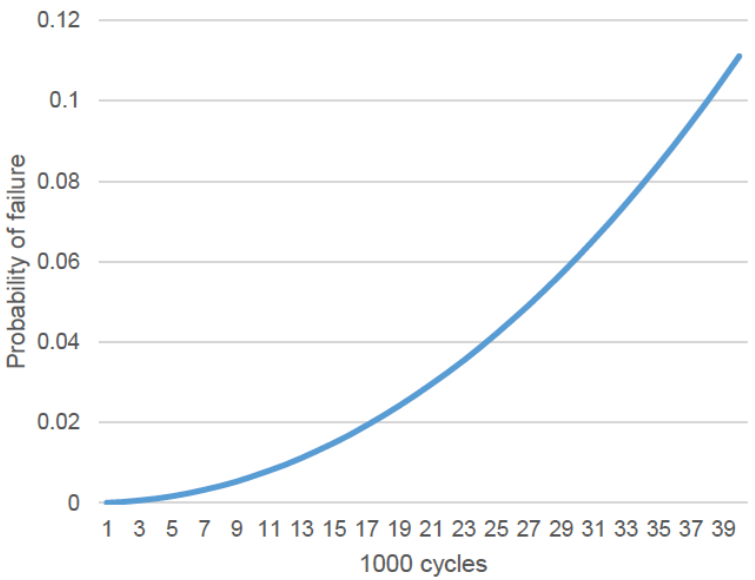
Example – Repair costs, material costs

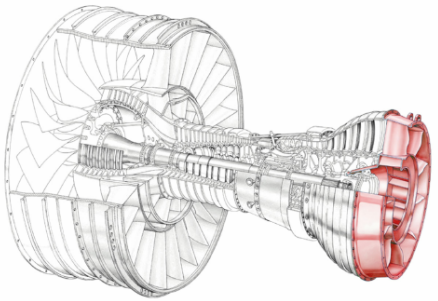
Weibull-distribution for probability of occurrence of failure

$$p_f = 1 - e^{-(\frac{N}{\lambda})^k}$$
$$\lambda = L * (\ln(0.9))^{-1/k}$$
$$k = 2$$

Repair Cost $c_6(N) = \beta_{maint} * p_f * N * q$

- Select Cost Estimating methods
- Integrate individual cost element models

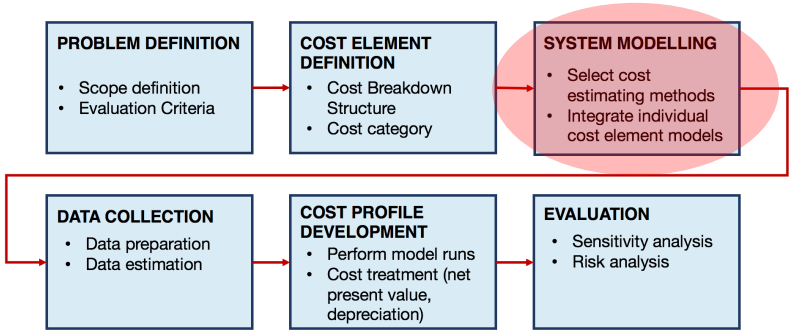




Example – Material costs

Weight	0.000833*N + 216.67
Materials	alpha_mat * W * q

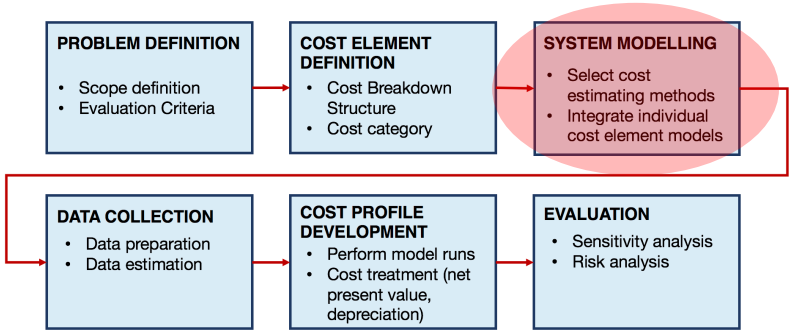
Cost Estimating methods



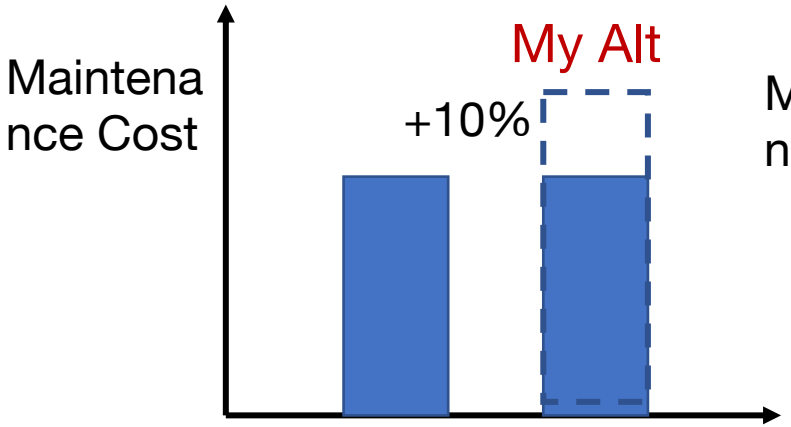
Analogous	It takes a similar product or system to the one being developed and adjusts its cost based on the differences between the two . The effectiveness of this method depends on the ability to correlate the appropriate cases and identify their differences. A major disadvantage of this method is the high degree of judgment required
Parametric	This technique typically uses regression analysis based on historical and technical data to form Cost Estimating Relationships.
Activity-based	Activity Based Costing (ABC) is a method which assigns the costs of activities to products and/or services according to how much the product/service has consumed. When the costs of the activities have been identified, the cost of each activity is attributed to each product to the extent that the product uses the activity.

Curran, R., Raghunathan, S. and Price, M., 2004. Review of aerospace engineering cost modelling: The genetic causal approach. *Progress in aerospace sciences*, *40*(8), pp.487-534.

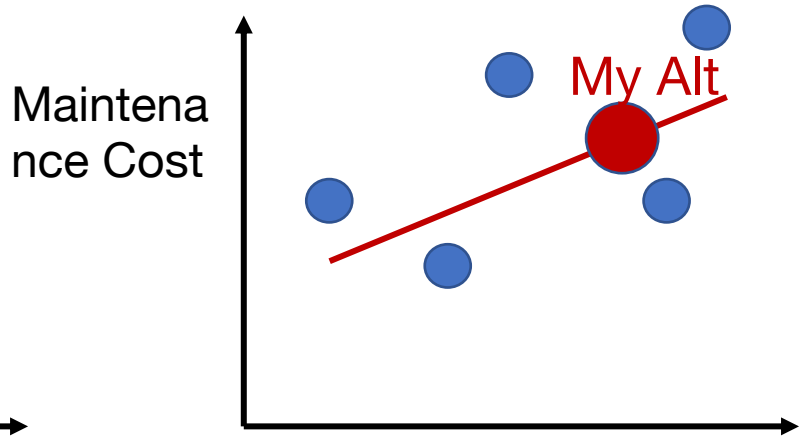
Cost Estimating methods



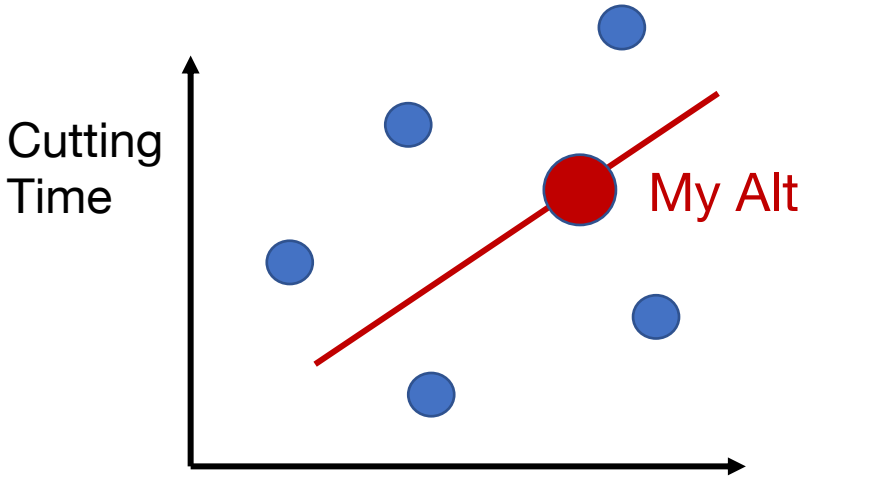
Maint.Cost = Cost per cutting time * cutting Time



Analogous

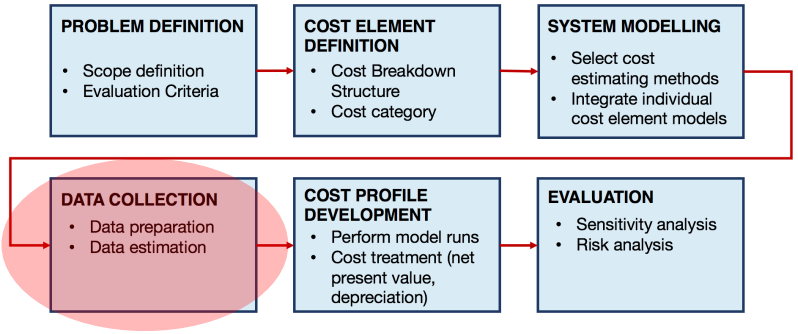


Parametric



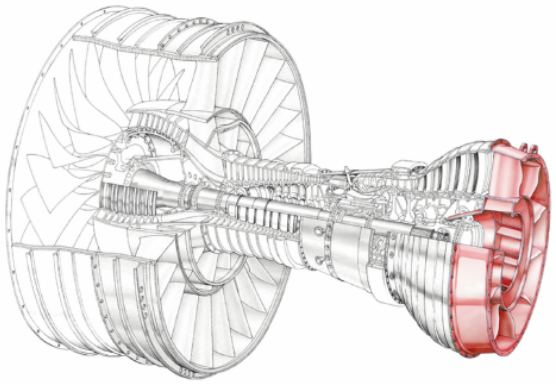
Activity-based

Data Collection

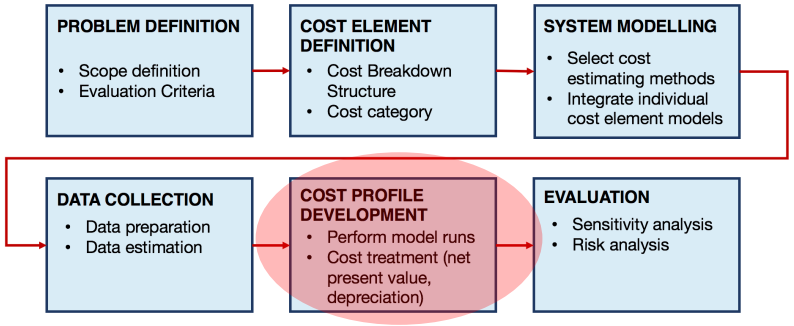


- Data Preparation
- Data estimation

Use phase			40000	cycles
Cycle length			1000	km
Use phases /year			1460	cycles/a
Material cost Inconel 718		alpha_mat	100	$/kg
Manufacturing cost	linearly interpolated	beta_man	3.33	$/cycle
		gamma_man	20000	$
Transportation cost		alpha_trans	4	$/kg
Fuel cost	2013 average jet fule prices		3.05	$/gallon
	0.29 gallons per kg per engine cycle	alpha_fuel	3560	$/kg
Replacement cost	service labor to install new TRS	gamma_repl	5000	$
Repair cost	linearly interpolated	beta_repair	1.42	$/cycle
Failure rate	Weibull distribution	k	2	
		lambda	123231.305	



Cost Profile Development



Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting to analyze the profitability of a projected investment or project.

Cost Treatment (Net Present Value)

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n}$$

Where

C_t = net cash inflow during the period t

C_o = total initial investment costs

r = discount rate, and

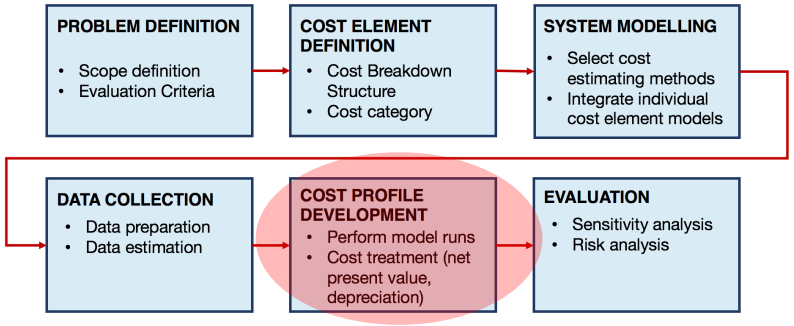
t = number of time periods

Discount rate is usually 6-8% for engineering products

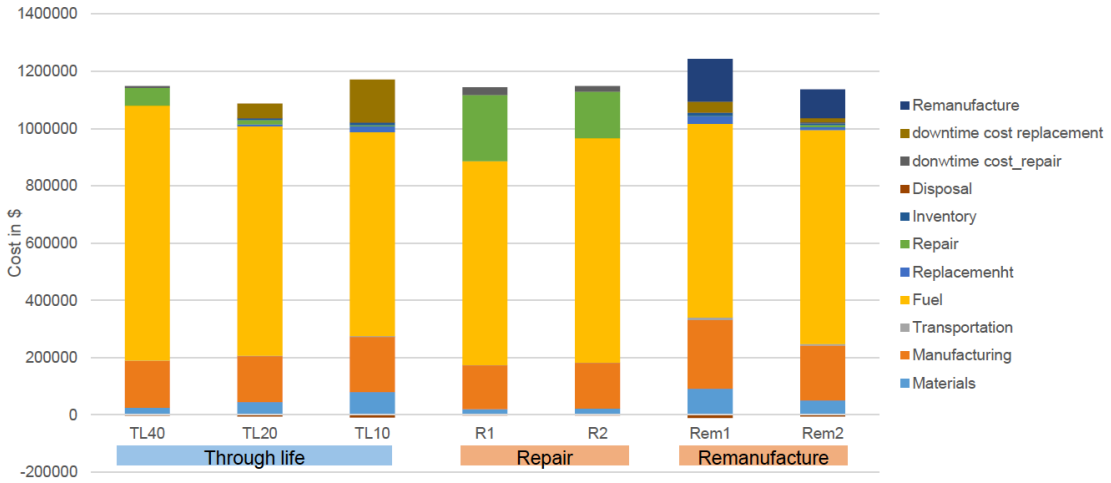
B11 | =B9/(1+B10)^B2

	A	B	C	D	E
1		year			
2	**Input**	0	1	2	3
3	Production Frames Troughput (frames/year)	130	150	100	80
4	Increase/decrease in throughput (%)	0.00%	0.00%	0.00%	0.00%
5	Adjusted production Troughput	130	150	100	80
6	**LCC Cost Items**				
7	Yearly LCC (SEK)	260000	300000	200000	160000
8					
9	Yearly LCC (SEK)	260000	300000	200000	160000
10	Discount rate (%)	0.06	0.06	0.06	0.06
11	Discounted LCC (Total LCC year)	260000	283018.868	177999.288	134339.085
12	Cumulative LCC over time (SEK)	260000	543018.868	721018.156	855357.241

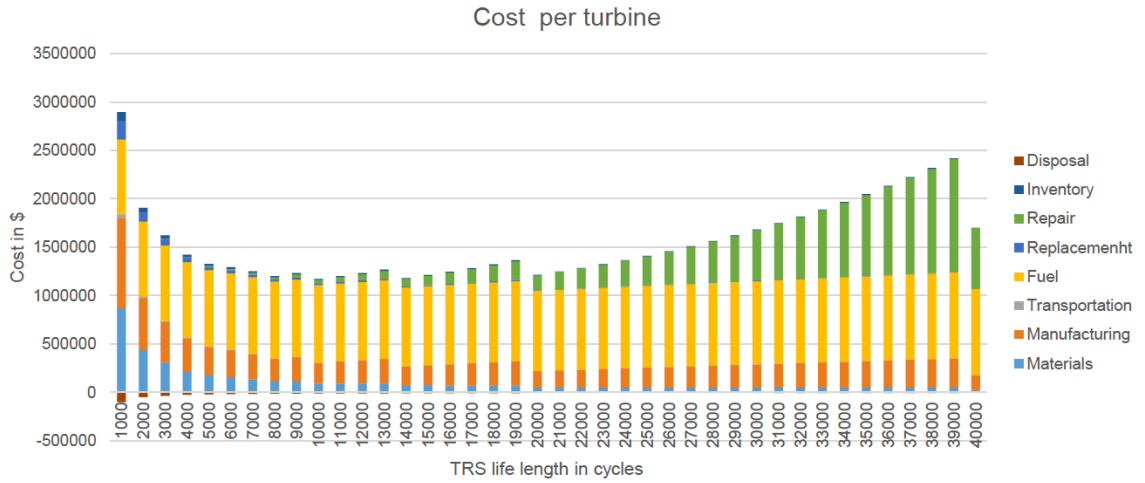
Perform Model runs



Life Cycle Costs for different scenarios

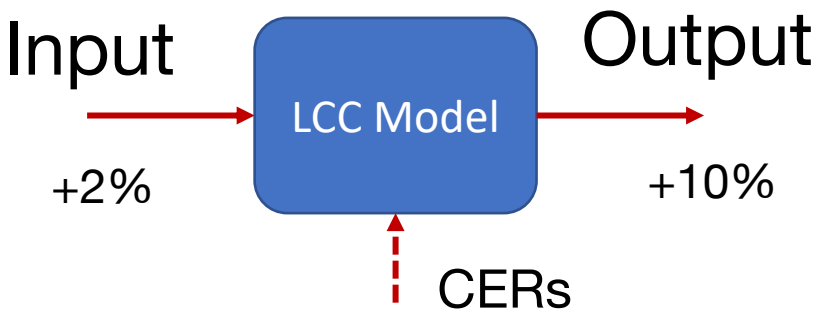


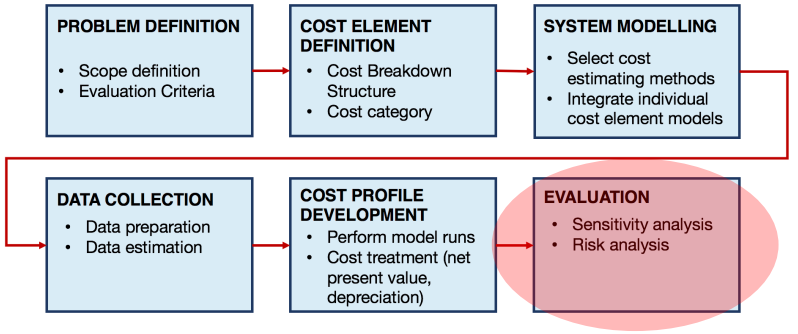
Life Cycle Length Optimization



Evaluation

Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model can be apportioned to different sources of uncertainty in its inputs. A related practice is uncertainty analysis, which has a greater focus on uncertainty quantification and propagation of uncertainty.





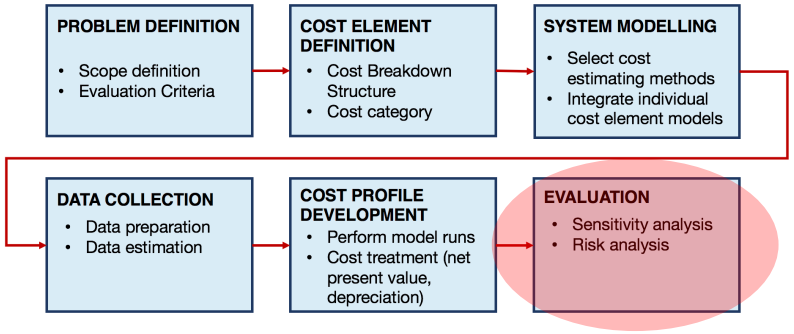
Sensitivity Analysis

If I increase the manufacturing cost per kilo by 10% how much does the result differentiate?

The result of the sensitivity analysis allow us to question or model

- The validity of the input data
- The cost estimating relationships

Evaluation



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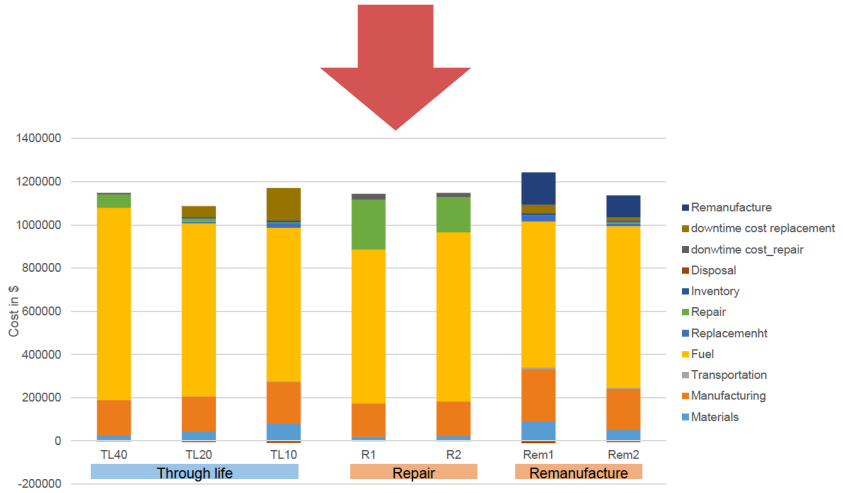

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THANKS!!!

Massimo Panarotto, Researcher,
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Division of Product development, Department of Industrial and Materials Science