Financial Aspects of Additive Manufacturing

Learning Outcome

You know cost levers of Additive Manufacturing

You know fundamental concepts of valuation

You know how to calculate Amortization, Net Present Value and Return on Investment

You are able to do AM cost calculations (polymer, metal)

1. Cost Levers in AM

AM Applications

Innovative Fabrication of Given Parts (case I: Fuel Nozzle, EOS)

Manufacturing of Optimized Parts (case II: Tooling, EOS)

Fabrication of New Parts

CASE I – Fuel Nozzle at “Company I”

- Production of fuel nozzles for aircrafts
- Production capacity 700 parts per year
- Cost per part €100
- Profit margin per part 5%

❑ Problem

e-Manufacturing Solutions

- Fuel nozzle are made up of 20 disparate parts procured from different suppliers
- Brazed and welded together
- Heat durability, weight, stability of components

❑ Possible Solutions

- AM production of fuel nozzle as a single part that replicates all twists, turns and interior chambers of the old fuel nozzle

❑ Investment and costs

- Investment for AM System €650,000 required + annual costs €40,000 for service contract and €60,000 for system operator

❑ Challenges

- Adaption to changes in markets
- Flexibility, introduction of AM facilities
- Increased cost
- Complexity of the adoption and modernising process
- Time constraints

❑ Prototyping

- Weight – AM fuel nozzle: 25% lighter than traditional product
- Five times stronger
- Cost saving approximately $3 million per Aircraft per year

→ Assumed Value add: 20%

- Return on investment and amortization?

CASE II – Tooling at "Company II"

- Production of power supply units for mobile phones and other devices
- Production of 800,000 units per year and annual production costs of €220,000
- Sales price €2 per unit, perfect market

❑ Problem

- Traditional tools: Drilling, turning etc. of cavities for cooling (hardening of the heat-liquefied plastic the supply units are made of)
- Traditional tools don´t allow further optimization of the cooling process due to limited form and design

❑ Possible Solutions

- Intensified cooling – bringing elements much more closer to the cavity
- New tools with complex cavities using AM

Investment

- Investment AM of €10 Mio required

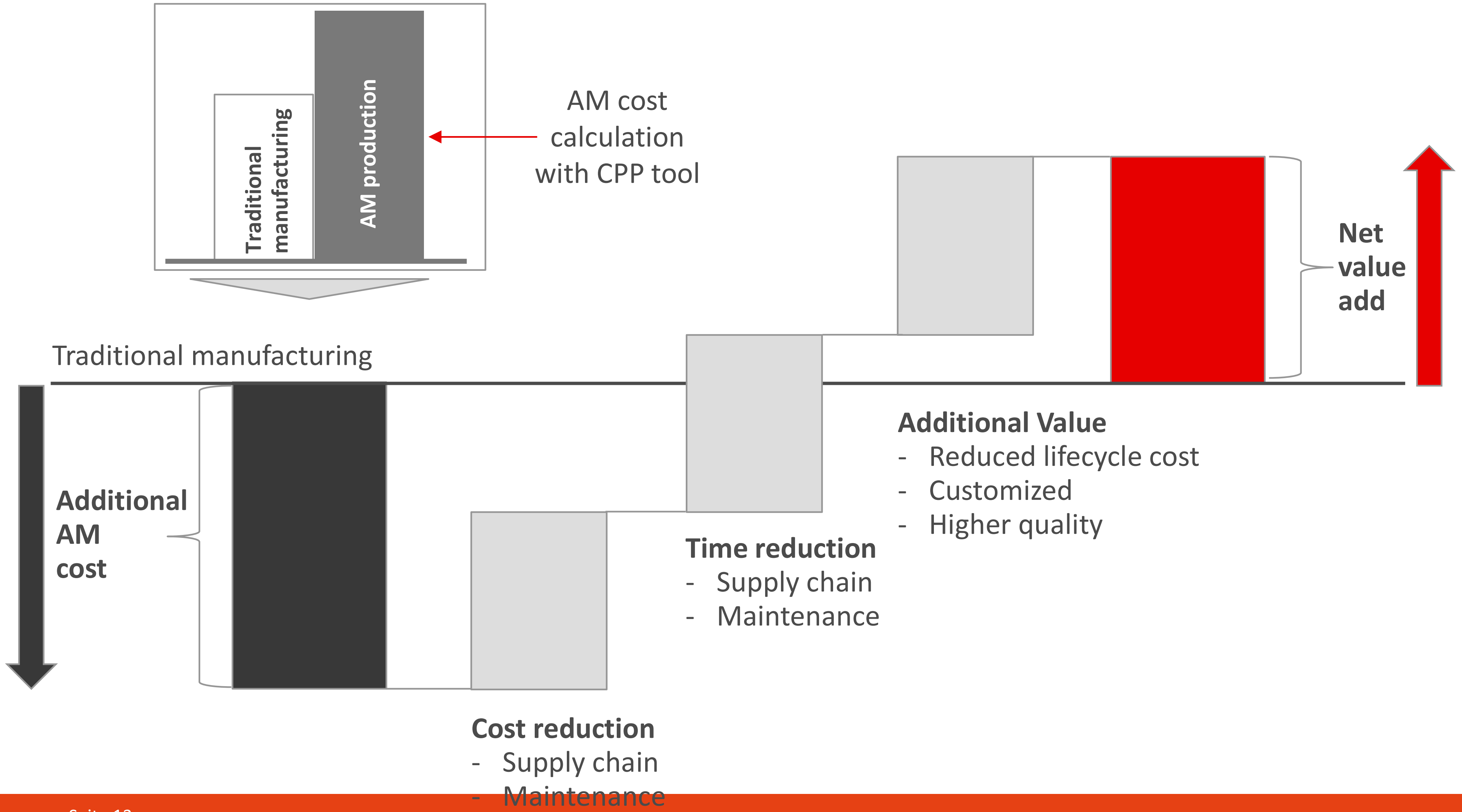
Challenges

- Key element to be improved
- Cooling process of finished products
- Time taken to cool the finished products

Prototyping

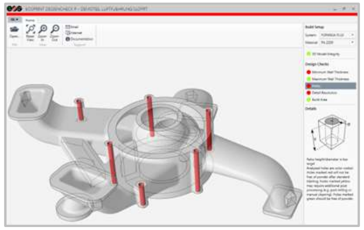
- Time required for cooling reduced from 14 to 8 seconds per production cycle
- Company could increase monthly output through efficiency gain by more than 56,000 units or 600,000 per year
- Very Important: Possible annual cost savings amount to €20,000
- Return on investment and amortization??

The overall aim is to leverage value add through additive manufacturing technology

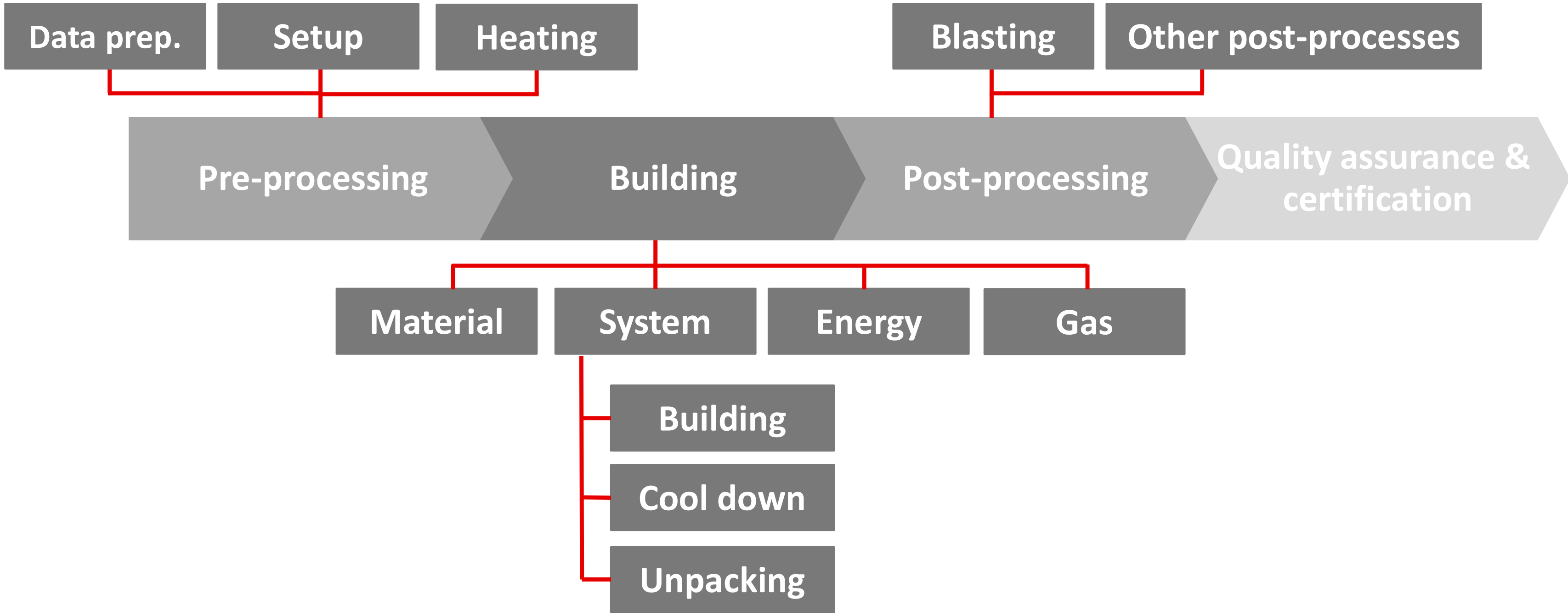


Cost levers are hidden in the whole AM production process

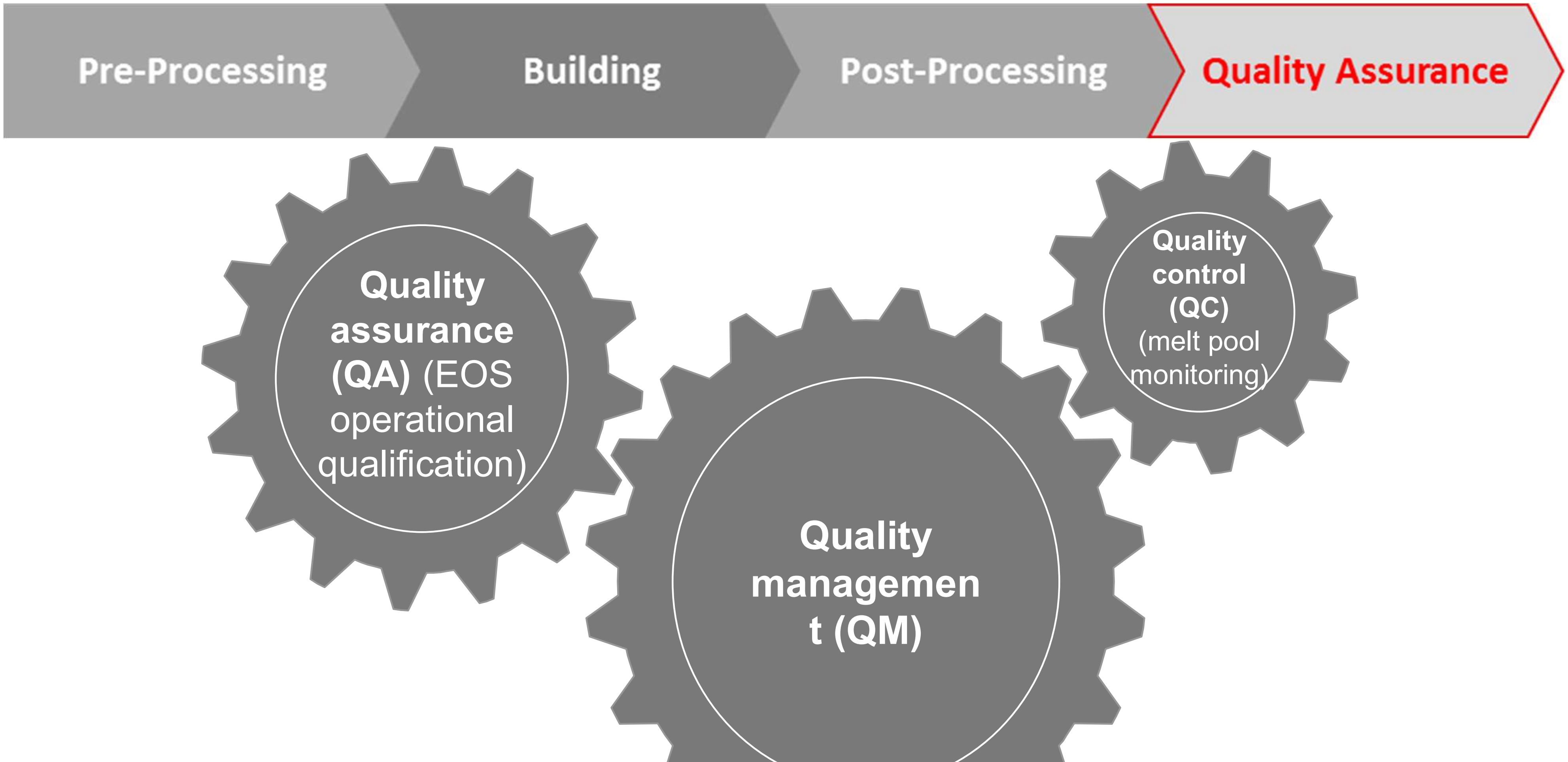
Pre-processing → Building → Post-processing → Quality assurance & certification



Summary Cost Levers in AM



Quality management is a very important and expensive cost driver in AM



Especially in the **aerospace** and **medical technology** industry where qualification processes are very costly and long lasting, very good OM is important

2. Fundamental Concepts of Valuation

Future Value and Compounding

Suppose you deposit €1 for one year at a rate of 9%. How much will it amount to in one year?

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What happens if you leave it in the account for another year?

Future Value and Compounding

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What happens if you leave it in the account for another year?

$€1 \times (1+r) \times (1+r) = €1 \times (1+r)^2$

$€1 \times (1.09) \times (1.09) = €1 \times (1.09)^2 = €1 + €0.18 + €0.0081 = €1.1881$

Future Value of an Investment:

$$FV = C_0 * (1+r)^T$$

Present Value of an Investment:

$$PV = C_t/(1+r)^T$$

Sometimes interest is charged more frequently than once per year

Semi-annually (2 times a year)	Quarterly (4 times a year)	Monthly (12 times a year)	Weekly (52 times a year)	Daily (365 times a year)	Continuous

Formula for compounding more than once a year

Compounding an investment ***m*** times a year provides end-of-year wealth of:

$$C_0\left(1+\frac{r}{m}\right)^{m*T}$$

Where $\boldsymbol{C_0}$ is the initial investment and **r** is the ***stated annual interest rate.***

The stated annual interest rate is the annual interest rate without consideration of compounding.

Effective Annual Rate

What is the end-of-year wealth if Christin Robinson receives a stated annual interest rate of 9 percent compounded monthly on a €1 investment?

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What is the end-of-year wealth if Christin Robinson receives a stated annual interest rate of 9 percent compounded monthly on a €1 investment?

$$€1\left(1+\frac{0.09}{12}\right)^{12} = €1 \times (1.0075)^{12} = €1.0938$$

The annual rate of return is 9.38 percent. This annual rate of return is called either the **effective annual interest rate (EAR)** or the **effective annual yield (EAY).**

Due to compounding, the effective annual interest rate is greater than the stated annual interest rate of 9 percent.

Formula for continuous compounding

Compound every infinitesimal instant:

$$C_0 \lim_{m\to\infty}\left(1+\frac{r}{m}\right)^{m*T}$$

where C_0 is the initial investment and **r** is the ***stated annual interest rate***.

Continuous Compounding

Compound every infinitestimal instant

$$FV = C_0 \times e^{rT}$$

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$$€1\ e^{0.09*1} = €1.0942$$

The annual rate of return is 9.42 percent.

3. Amortization, Net Present Value and Return on Investment

Time

	0	1	2	3	…..	T
Investments	I_o	I_1	I_2	I_3		I_T
Operational		O_1	O_2	O_3		O_T

Assume interest rate r over period T, compound factor q = 1+r

Capital Value at Period T = Annual Capital Payback A

$$I_0 q^T + (I_1 + O_1)q^{T-1} + (I_2 + O_2)q^{T-2} + \dots = A\left(q^{T-1} + q^{T-2} + \dots\right) \qquad | : q^T$$

$$I_0 + (I_1 + O_1)q^{-1} + (I_2 + O_2)q^{-2} + \dots = A\left(q^{-1} + q^{-2} + \dots\right)$$

$$I_0 + \sum_{t=1}^{T}(I_t + O_t)q^{-t} = A \sum_{t=1}^{T} q^{-t}$$

$$I_0 + \sum_{t=1}^{T} (I_t + O_t) q^{-t} = A \sum_{t=1}^{T} q^{-t}$$

$$I_0 + \sum_{t=1}^{T} (I_t + O_t) q^{-t} = A \frac{q^T - 1}{r\, q^T}$$

$$A = \left(I_0 + \sum_{t=1}^{T} (I_t + O_t) q^{-t}\right) \frac{r\, q^T}{q^T - 1}$$

$$A = \left(I_0 + \sum_{t=1}^{T} (I_t + O_t) q^{-t}\right) \frac{r}{1 - q^{-T}}$$

In case that I_t and O_t are constant every year

$$\mathbf{A} = \left(I_0 + (I + O) \sum_{t=1}^{T} q^{-t} \right) \frac{r}{1 - q^{-T}}$$

$$\mathbf{A} = \left(I_0 + (I + O) \frac{q^T - 1}{r\, q^T} \right) \frac{r}{1 - q^{-T}}$$

$$\mathbf{A} = \mathbf{I}_0 \frac{r}{1 - q^{-T}} + I + O$$

Time

	0	1	2	3	.....	T
Investments	I_o	I_1	I_2	I_3		I_T
Operational		O_1	O_2	O_3		O_T
Turnover/Sales		S_1	S_2	S_3		S_T

Assume interest rate r over period T, compound factor q = 1+r

Capital Value at Period T (Return on Investment ROI)

$$ROI = -I_0 q^T + (-I_1 - O_1 + S_1)q^{T-1} + (-I_2 - O_2 + S_2)q^{T-2} + \dots$$

$$= [-I_0 + (-I_1 - O_1 + S_1)q^{-1} + (-I_2 - O_2 + S_2)q^{-2} + \dots]\, qT$$

$$= [-I_0 + \sum_{t=1}^{T}(-I_t - O_t + St)q^{-t}]\, qT$$

Net Present Value (NPV)

$$\mathrm{NPV} = ROI/qT = -I_0 + \sum_{t=1}^{T}(-I_t - O_t + St)q^{-t}$$

Summary Payback Rate, ROI and NPV

- Annual Capital Payback Rate: $A = \left(I_0 + \sum_{t=1}^{T}(I_t + O_t)q^{-t}\right) \frac{r}{1-q^{-T}}$

in case of constant I_t , O_t: $A = I_0 \frac{r}{1-q^{-T}} + I + O = I_0 \frac{rq^T}{q^T-1} + I + O$

- Net Present Value: $NPV_T = -I + \sum_{t=1}^{T}(S_t - I_t - Ot)(1+r)^{-t}$

- Return on Investment: $ROI_T = NPV_T\,(1+r)^T$

I – Investment
T – Period (depreciation)
r – Interest Rate
S_t – Revenues, Sales in year t
I_t – Investments in year t (e.g. spare parts, etc.)
O_t – Operational Costs in year t

Investment useful if NPV>0

4. Financial calculation AM – Polymer

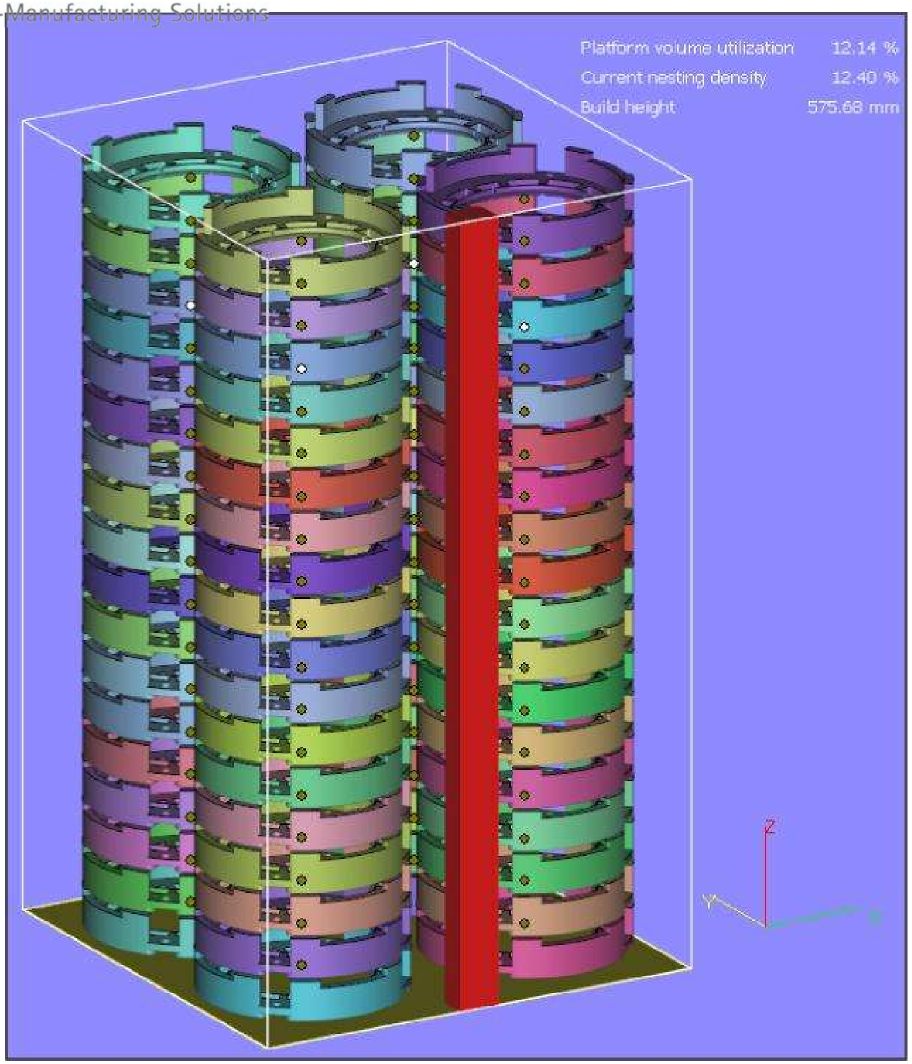
Job Cost € = Build time h × Machine Cost rate €/h + Material Used kg × Material Cost €/kg

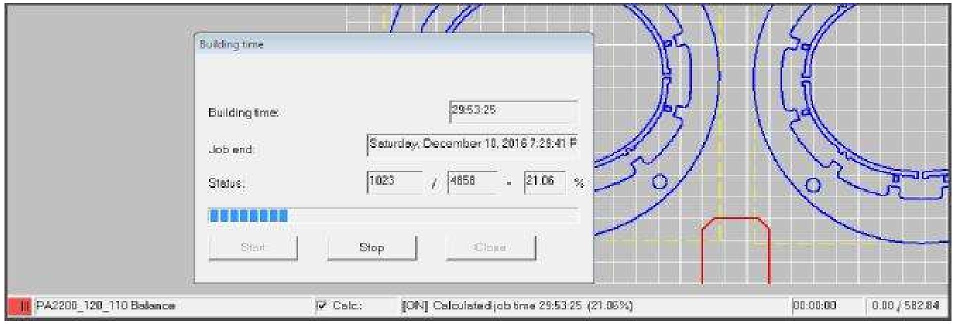
Build time:
- Calculated in job preparation software

Machine Cost rate:
- Investment cost
- Service & Consumables
- Depreciation period
- Utilization / year

Material Used:
- Part Volume
- Part Bounding Box
- Utilization of build area

e-Manufacturing Solutions





Machine Type	P 396
Parts per job	72
Parameter set	120µm EOS UD
Building Time	30h

Build times can be calculated accurately when stacking a job

Example for P396

e-Manufacturing Solutions

Investment cost

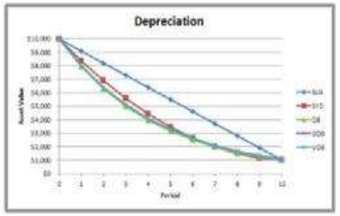
- Basic system
- Periphery
- Accessories
- Powder Handling

300,000 €

Service & Consumables

- Service Contract
- Software Licenses
- Power
- Rent

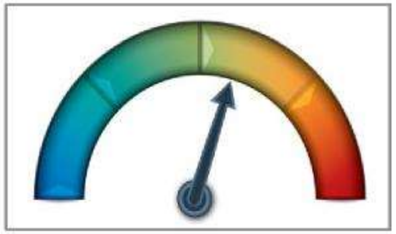
30,000 €/year



Depreciation Period

- Machine runs longer than depreciation period
- Depreciation due to technological progress

5 years



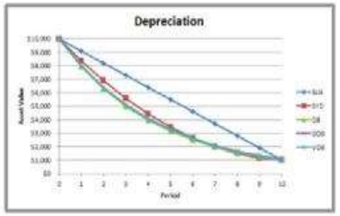
Utilization/year

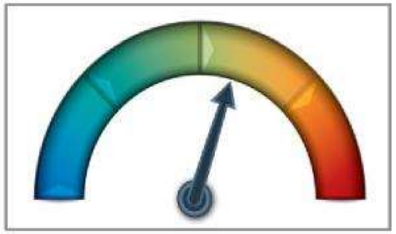
- Long build times lead to high utilization
- Prototyping: 1,000-2000
- Serial Production: 5,000 h

5,000 hours

Example for P396

e-Manufacturing Solutions





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Utilization/year

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5,000 hours

$$Annual\ Machine\ Cost = 300{,}000\ € \frac{0.05 \cdot 1.05^5}{1.05^5 - 1} + 30{,}000\ € = 99{,}300\ €$$

$$Machine\ Cost\ per\ hour = \frac{99{,}300\ €}{5{,}000\ h} = 19.86\ €/h$$

Material Used kg = Melted Material + Waste Material

Melted Material:
- Density of Melted Material
- Part Volume

Waste Material:
- Fill Rate
- Density of unmelted Material
- Refreshment rate

Volume Parts [cm³]	7,729
Volume Bounding Boxes (job height x platform area [cm³]	66,470
Density Sintered PA 2200 [g/cm³]	0.93
Powder Density PA 2200 [g/cm³]	0.45
Refreshment rate	50%

Material Used kg = **Melted Material** + **Waste Material**

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Exemplary calculation: Powder usage = 7,729 cm³ * 0.93g/cm³ + (66,470-7,729)*0.45*50%

PA2200 **7.18 kg** **13.22 kg** **= 20.4 kg**

Job Cost € = Build time h * Machine Cost rate €/h + Material Used kg * Material Cost €/kg

Job Cost € = 30 h * 20 €/h + 20 kg * 64 €/kg

Job Cost **€** = Build time **h** * Machine Cost rate **€/h** + Material Used **kg** * Material Cost **€/kg**

Job Cost **€** = 30 **h** * 20 **€/h** + 20 **kg** * 64 **€/kg**

Job Cost **€** = 600 **€** + 1,280 **€**

Job Cost € = Build time h * Machine Cost rate €/h + Material Used kg * Material Cost €/kg

Job Cost € = 30 h * 20 €/h + 20 kg * 64 €/kg

Job Cost € = 600 € + 1,280 €

Job Cost € = 1,880 €

Job Cost € = Build time h * Machine Cost rate €/h + Material Used kg * Material Cost €/kg

Job Cost € = 30 h * 20 €/h + 20 kg * 64 €/kg

Job Cost € = 600 € + 1,280 €

Job Cost € = 1,880 €

Cost by Part € = 1,880 € / 72 parts = 26.10 €

5. Financial calculation AM – Metal

Case: Fuel Nozzle

Facts:
So far: production of 700 parts, cost pp €100, profit margin pp 5%

Additive Manufacturing of fuel nozzles:

- Investment €650,000 for the AM system, annual operational expense of €40,000 for service contract and €60,000 for system operator, system utilization 5,000h
- Material for AM: IN718 with specific cost of 140€/kg and density 8.15g/cm^3, support structure takes 10% more material and material losses of 5% are assumed
- AM job characteristics: Volume of parts per job 85cm^3 with 5 parts per job, build time per job 17h
- Value add 20%

Interest rate 5%

Cost Calculation Formula Metal

Job cost € = Machine Cost € + Material Cost €

Machine Cost € = Build time h ✖ Machine Cost Rate €/h

Material Cost € = Material Used kg ✖ Specific Material Cost €/kg

Cost Calculation Formula Metal

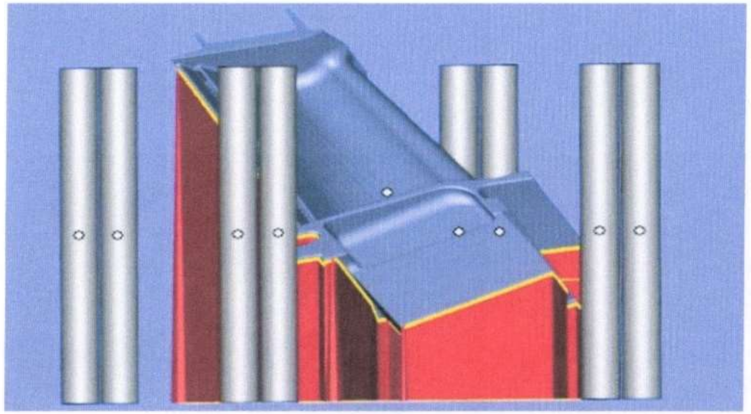
Job cost € = Build time h × Machine Cost Rate €/h + Material Used kg × Specific Material Cost €/kg

Calculated in Job Preparation Software

Investment Cost
Service & Consumables
Depreciation Period
Utilization / Year

Part Volume
Support Volume
Material Losses

Exemplary Calculation of job duration

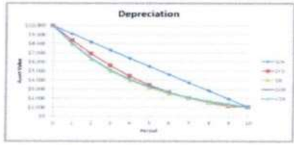
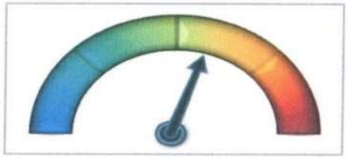


Machine Type	M 290
Parts per job	9
Material	NickelAlloy IN718
Volume (cm^3)	85
Parameter set	DirectPart (40µm)
Building Time	**17 h**

Build time can be calculated accurately when preparing a build job

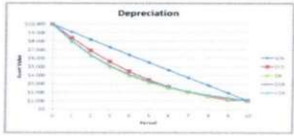
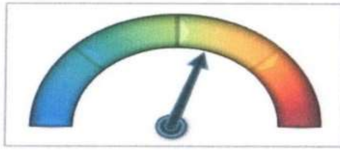
Example for M290

e-Manufacturing Solutions

Investment cost	Service & Consumables	Depreciation Period	Utilization/year
			
▪ Basic system ▪ Periphery ▪ Accessories ▪ Powder Handling	▪ Service Contract ▪ Software Licenses ▪ Power ▪ Rent	▪ Machine runs longer than depreciation period ▪ Depreciation due to technological progress	▪ Long build times lead to high utilization ▪ Prototyping: 1,000 - 2000 ▪ Serial Production: 5,000 – 6,000
650,000 €	**40,000 €/year**	**5 years**	**5,000 hours**

Example for M290

e-Manufacturing Solutions

Investment cost	Service & Consumables	Depreciation Period	Utilization/year
		 	
▪ Basic system ▪ Periphery ▪ Accessories ▪ Powder Handling	▪ Service Contract ▪ Software Licenses ▪ Power ▪ Rent	▪ Machine runs longer than depreciation period ▪ Depreciation due to technological progress	▪ Long build times lead to high utilization ▪ Prototyping: 1,000 - 2000 ▪ Serial Production: 5,000 – 6,000
650,000 €	**40,000 €/year**	**5 years**	**5,000 hours**

$$Annual\ Machine\ Cost = 650{,}000\ € \ \frac{0.05 \cdot 1.05^5}{1.05^5 - 1} + 40{,}000\ € = 190{,}133.619\ €$$

$$Machine\ Cost\ per\ hour = \frac{190{,}133.619\ €}{5000\ h} = 38.03\ €/h$$

Example for NickelAlloy IN718

e-Manufacturing Solutions

Material Used kg = **Melted Material** + **Waste Material**

Melted Material: Density of sintered Material, Part Volume

Waste Material: Support, Material Losses

Volume Parts [cm³]	85
Density NickelAlloy IN718 [g/cm³]	8.15
Support Factor	10%
Material Losses	5%

Exemplary calculation: Powder usage IN718 = 85 cm³ * 8.15 g/cm³ **0.69 kg** + 15% **0.10 kg** = **0.79 kg**

17 h
Build time

×

38€/h
Machine Cost rate

+

0.79 kg
Material Used

×

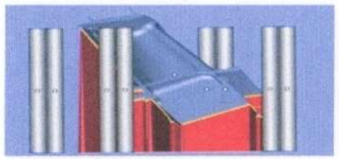
140 €/kg
Material Cost

646 €
Machine Cost

+

110 €
Material Cost

=



756 €
Job Cost

More detailed calculations by a simple Excel Tool

Study the influence of

- Investment cost
- Maintenance costs
- Postprocessing
- Qualification and training costs
- Build time
- Utilization per year
- Powder price
- Support volume and material losses
- Depreciation period
- Interest rate

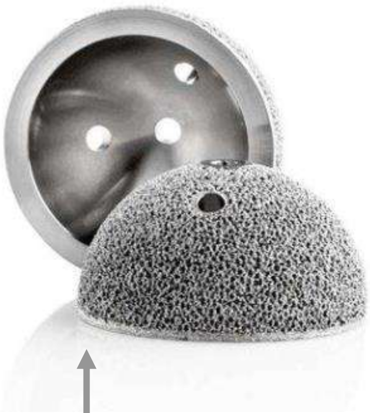
on Amortization and ROI

❑ CONCLUSION

Additive Manufacturing offers:

- High value add due to higher quality
- High ROI and short amortization
- Qualification is important to shorten the learning phase (high utilization per year)
- Build time has strong influence on the amortization and ROI → Optimal Design is important
- Smart cost optimization can reduce production costs by 20-30%

Example: Through smart cost optimization production cost can be reduced by 26%

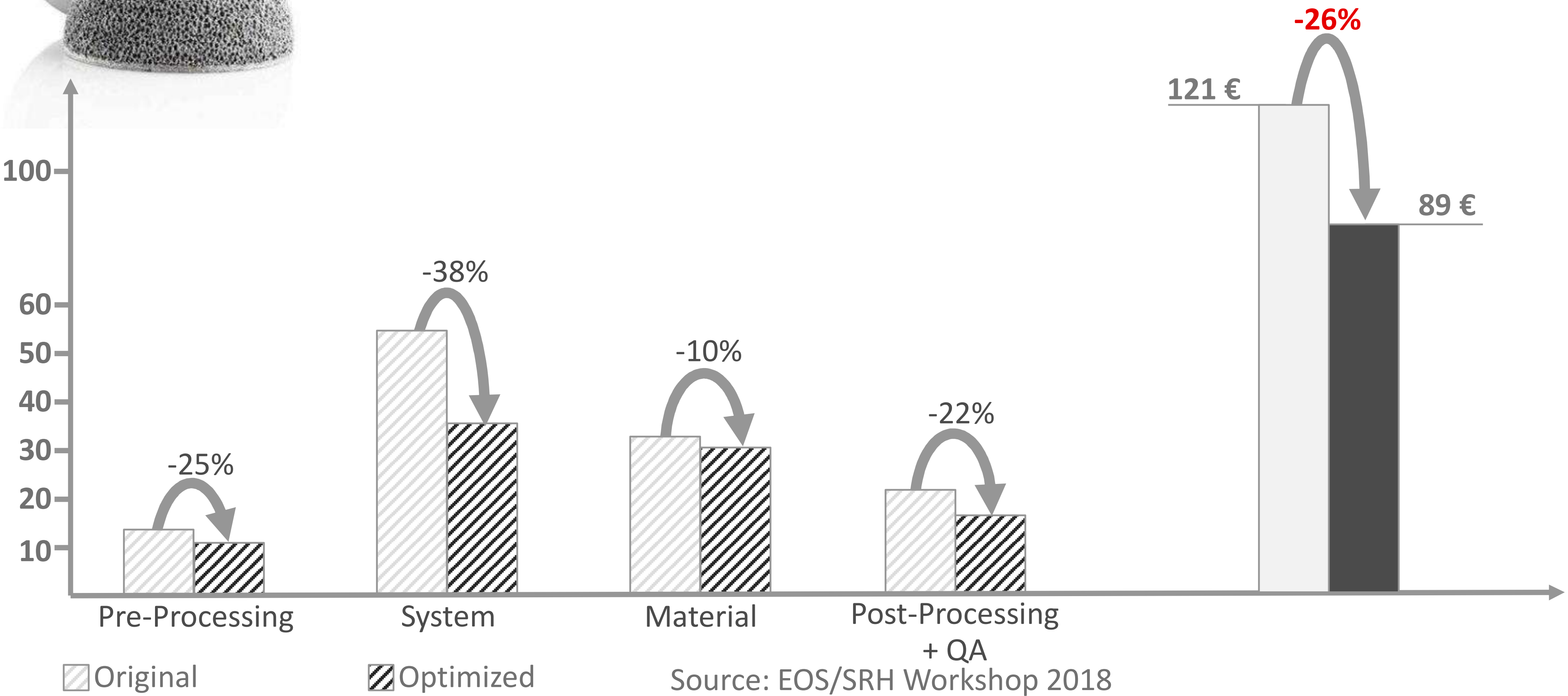


First iteration

▪ Pre-Processing:	12,00 €/part
▪ System:	55,00 €/part
▪ Material:	31,00€/part
▪ Post-Processing/QA:	23,00 €/part

Optimized

▪ Pre-Processing:	9,00 €/part
▪ System:	34,00 €/part
▪ Material:	28,00€/part
▪ Post-Processing/QA:	18,00 €/part



Source: EOS/SRH Workshop 2018

Thank you!