Cost modelling - a tool for sustainable innovation

Dr. Martyn D. Wakeman
martyn.wakeman@epfl.ch

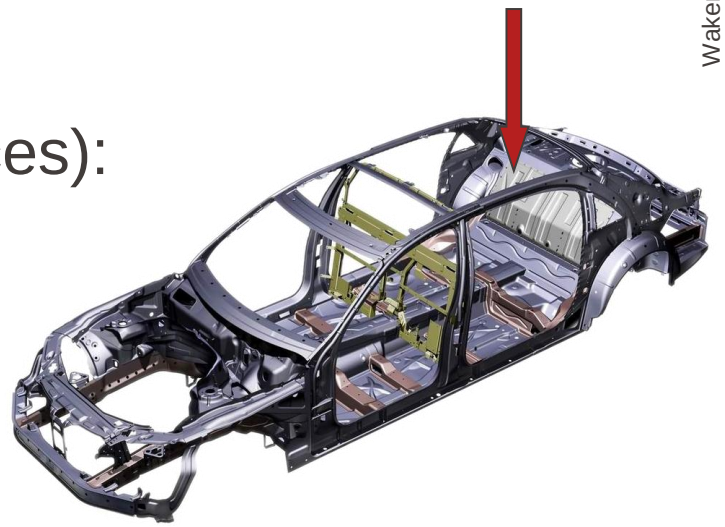
Prof. Veronique Michaud
veronique.michaud@epfl.ch

A simple cost model to try out …

- See Template Provided

Simple technical cost model	Process Totals	Die casting	Punching	Machining
Process Goals				
Material 1 mass per part (kg)	2.2			
Material 2 mass per part (kg)				
Target production rate (p/yr)	**120,000**			
Production duration (yrs)	5			
Dashboard				
Hours per shift (hrs/d/sh)	7.3			
Days per year (d/yr)	220			
Available shift operational time at 100% efficiency (hr/yr/shift)		1,606	1,606	1,606
Time efficiency (.)		80%	80%	80%
Available shift operational time (hr/yr/shift)		1,285	1,285	1,285
Cycle time (s/p)		110	90	60
Available shift production rate (p/yr/sh)		42,048	51,392	77,088
Required production rate OUT (p/yr)		120,000	120,000	120,000
Reject (.)		5%	0%	2%
Actual production rate IN (p/yr)		125,654	120,000	122,449
Single shift utilisation (.)		2.99	2.33	1.59
No of shifts required (sh)	3	3	3	2
Max no of shifts (sh)	3	3	3	3
No of shifts employed (sh)		3	3	2
Available production rate (p/yr)		126,144	154,176	154,176
Actual utilisation rate (.) MUST BE < 1	**1.00**	1.00	0.78	0.79
Available operational time (hrs/yr)		4,818	4,818	3,212
Actual operational time (hrs/yr)		4,799	3,750	2,551
Dedicated / Utilised		dedicated	dedicated	dedicated
Effective utilisation (.)		1.00	1.00	1.00
Material 1 Cost				
Material mass per part OUT (kg/p)		3.09	2.32	2.20
Scrap (.)		0%	25%	5%
Material mass per part IN (kg/p)		3.09	3.09	2.32
Material mass IN per year (kg/yr)		387,986	370,526	283,566
Material cost (€/kg)		3.2	0	0
Annual material cost IN (€/yr)		1,241,554	0	0
Material 1 value IN (€/p)	**10.35**	10.35	0.00	0.00
Material 2 Cost				
Material mass per part OUT (kg/p)				
Scrap (.)				
Material mass per part IN (kg/p)				
Material mass IN per year (kg/yr)				
Material cost (€/kg)				
Annual material cost IN (€/yr)				
Material 2 value IN (€/p)				

Exercise - Questions



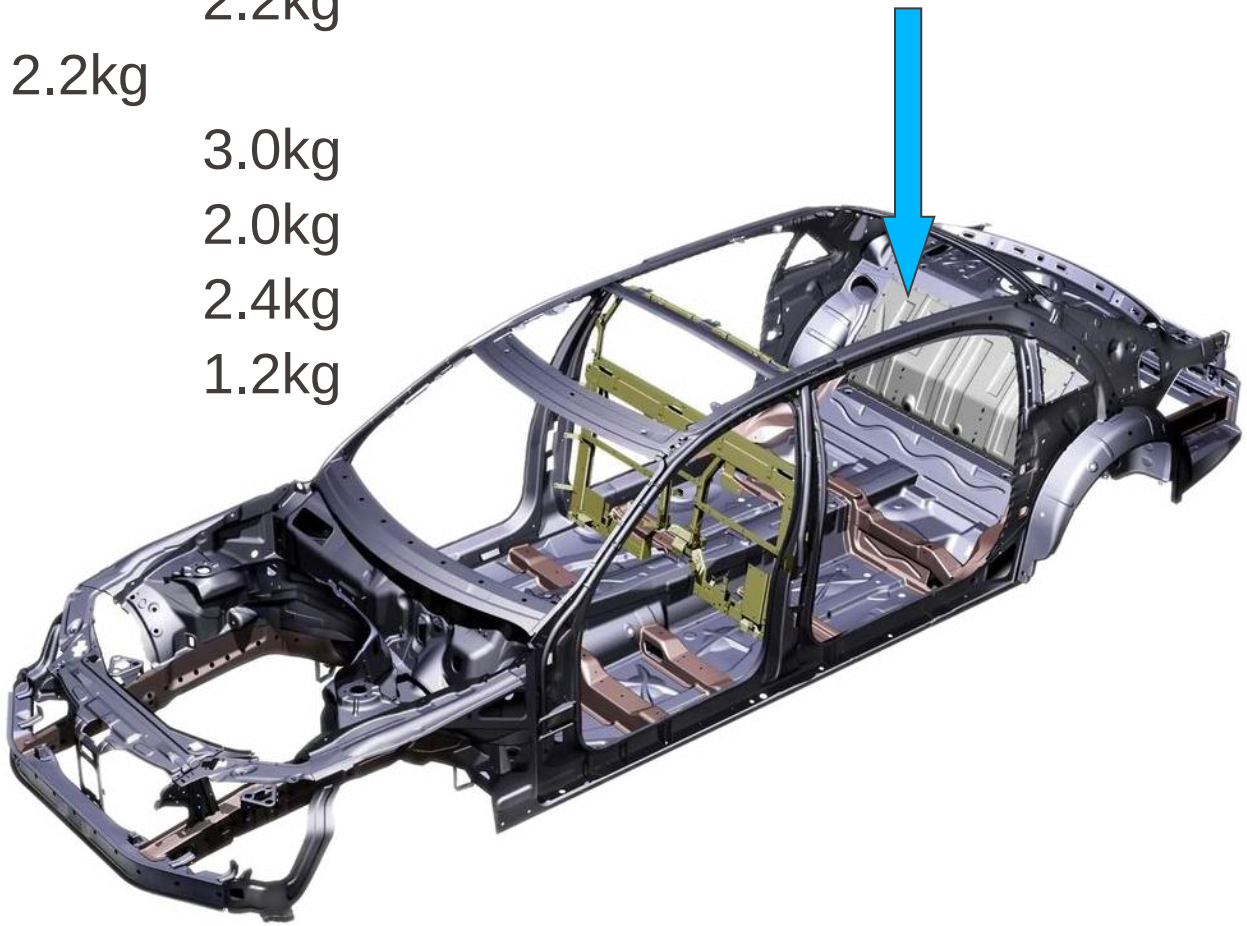
- Find the following for your chosen process (5 choices):
  - To meet the Max target production volume
    - Utilisation rate
    - Number of shifts required
    - Number of tools required
  - Production capacity (parts/yr) i.e. 100% utilisation
  - Total production cost
    - Including cost segmentation (materials, energy, labour etc)
  - Total Investment in equipment
  - Plot Cost vs. Volume as a sensitivity analysis
    - for 5k to 300k parts/yr
  - Plot Cycle Time vs. Total Cost as a sensitivity analysis (!)
    - Comment on addition of parallel of machines
  - Investigate the sensitivity of one other relevant parameter

Additional Questions

- Adapt the model
  - to multiply machines in parallel for utilisation > 1
  - Find the time interval (yrs) for investment in:
    - Tooling
    - Machines
  - Plot Investment vs.Time

Example Part

- Rear Structural Bulkhead, steel 5.8kg
  - Magnesium 2.2kg
  - GF NCF/Epoxy 2.2kg
  - SMC 3.0kg
  - GF/PA Fabric 2.0kg
  - GF/PA GMT 2.4kg
  - CF prepreg 1.2kg



Material costs for exercise

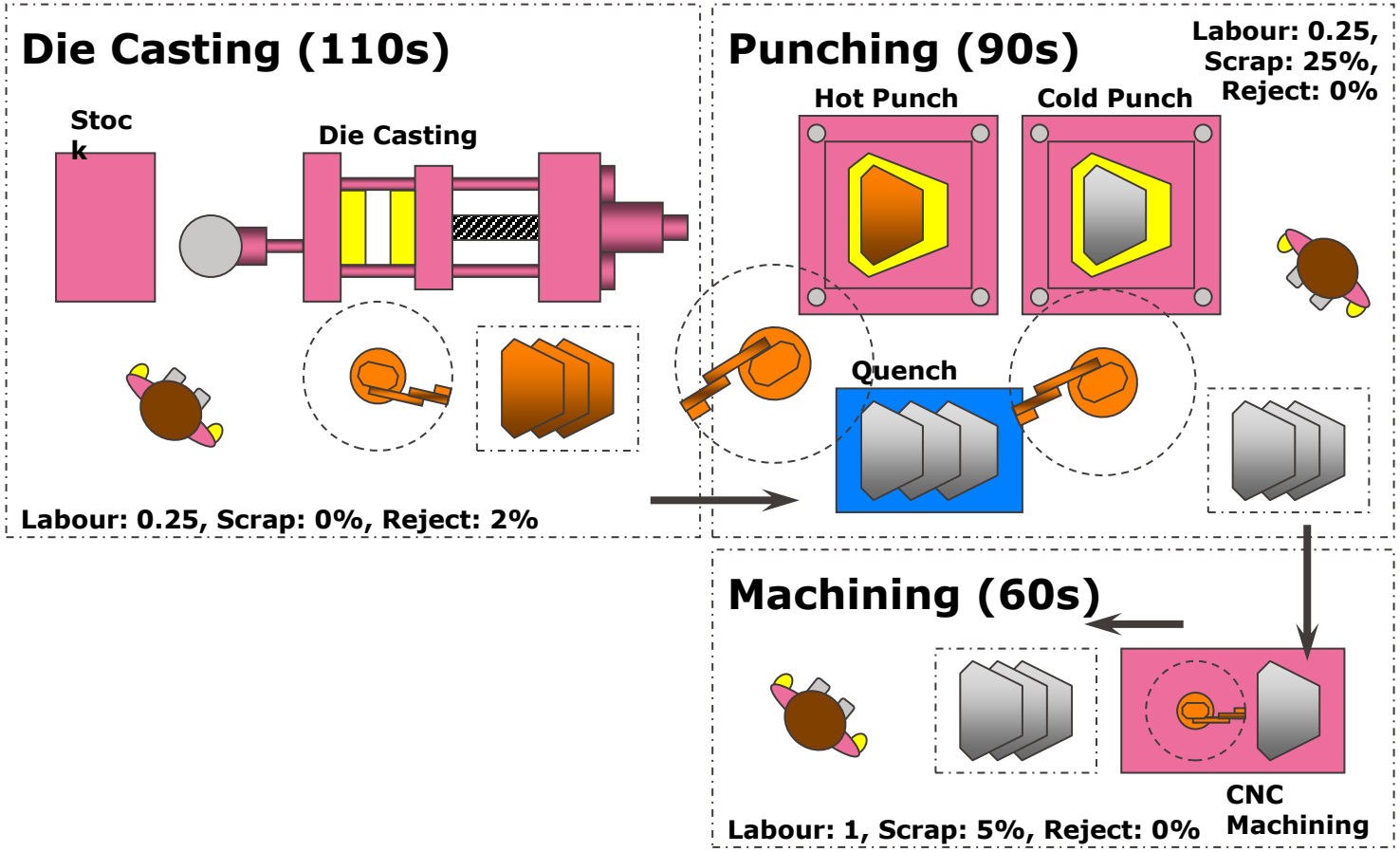
- Material Costs
  - Magnesium €2.2 /kg
  - Glass NCF €3.2 /kg
  - Epoxy resin €4.0 /kg
  - SMC €1.6 /kg
  - Glass / PA Fabric €7.0 /kg
  - PA GMT €6.0 /kg
  - CF prepreg €25 /kg

Production scenario data for exercise

- Production Scenario
  - 50’000, 100’000 and target of 300’000 parts per year
  - 5 years series production
  - 7.3hr/shift
  - 220 days per year
  - Max 3 shifts per day
  - Labour cost - direct €48/hr, indirect €56/hr
  - Indirect/Direct labour ratio of 0.75
  - Energy cost €0.18/kWh
  - Plant operating cost €140/m^2/yr
  - Machine lifetime 7yrs

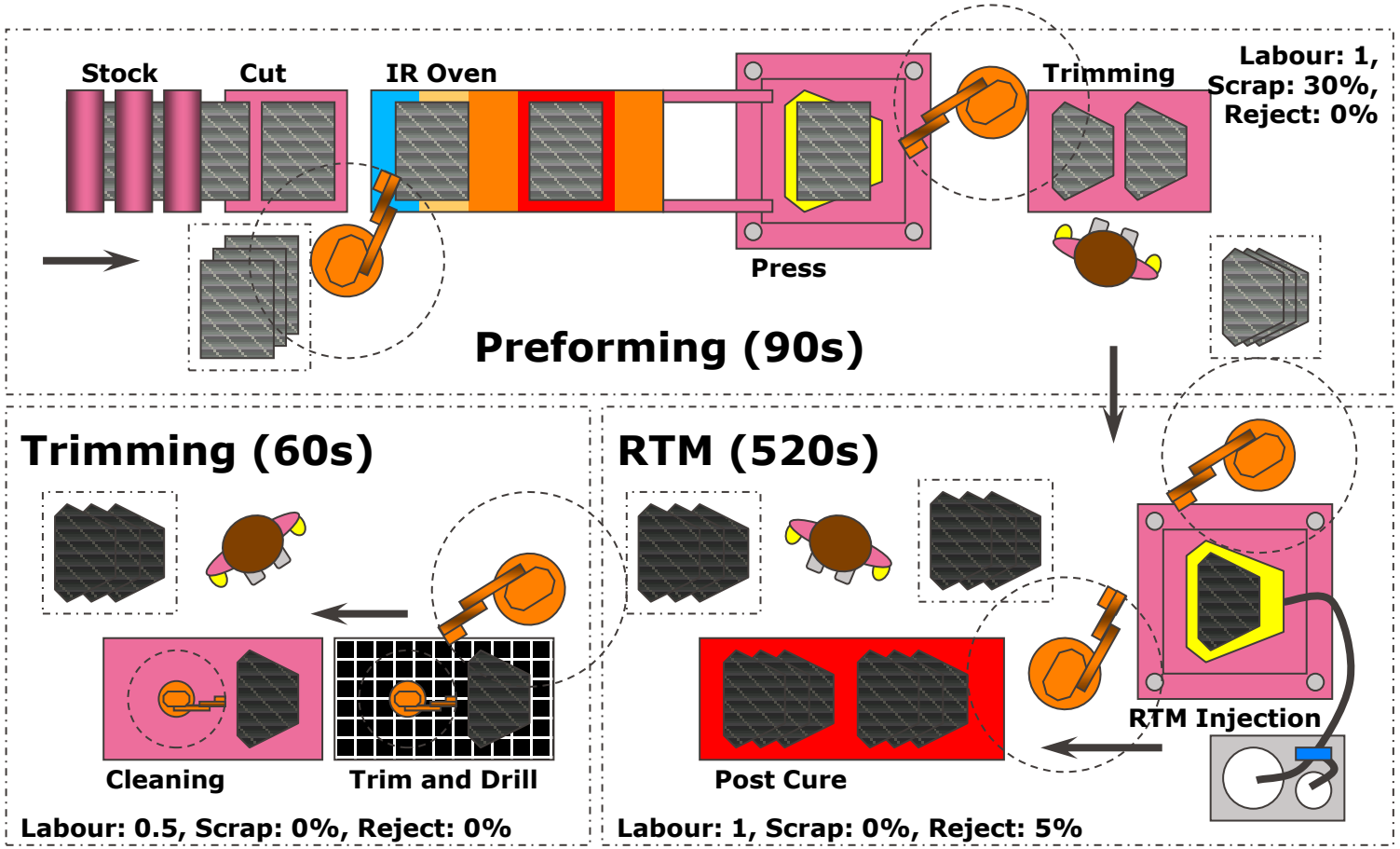
Example Process 1

- Magnesium Die Casting



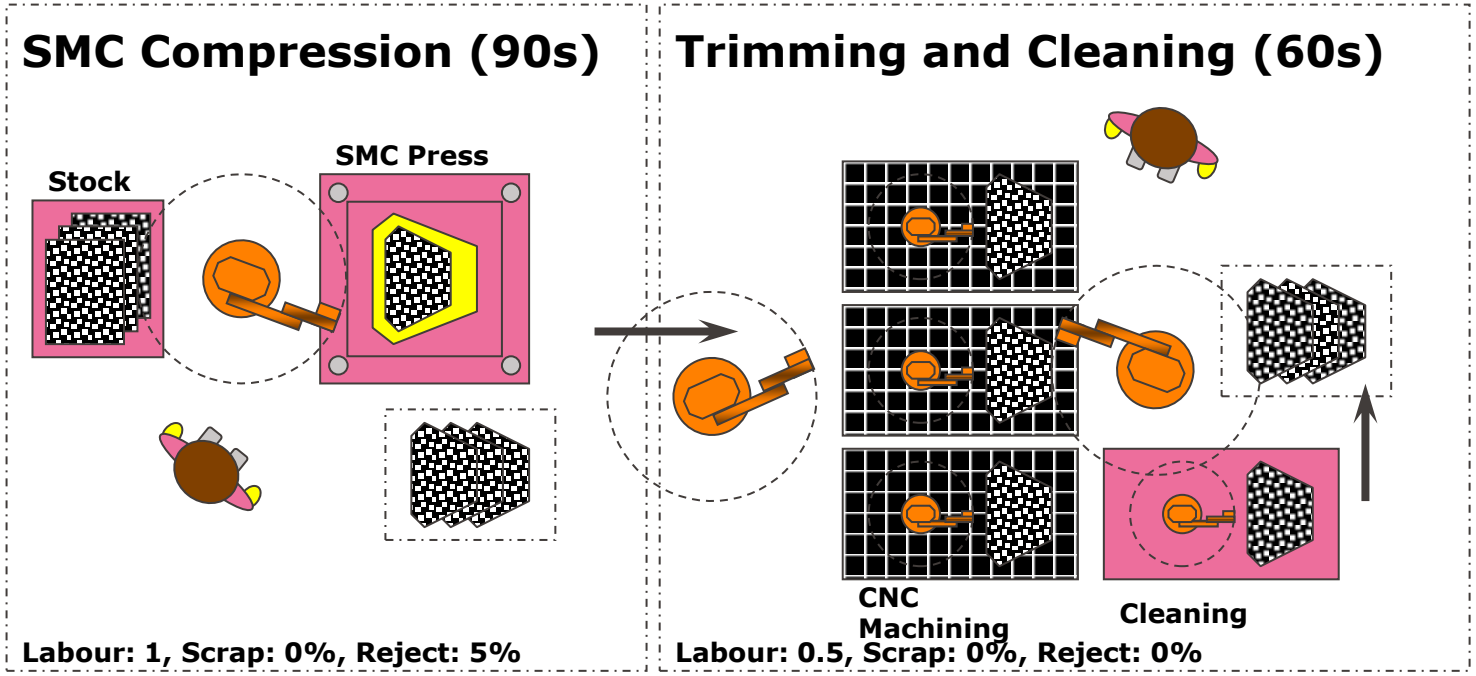
Example Process 2

- NCF / Epoxy RTM



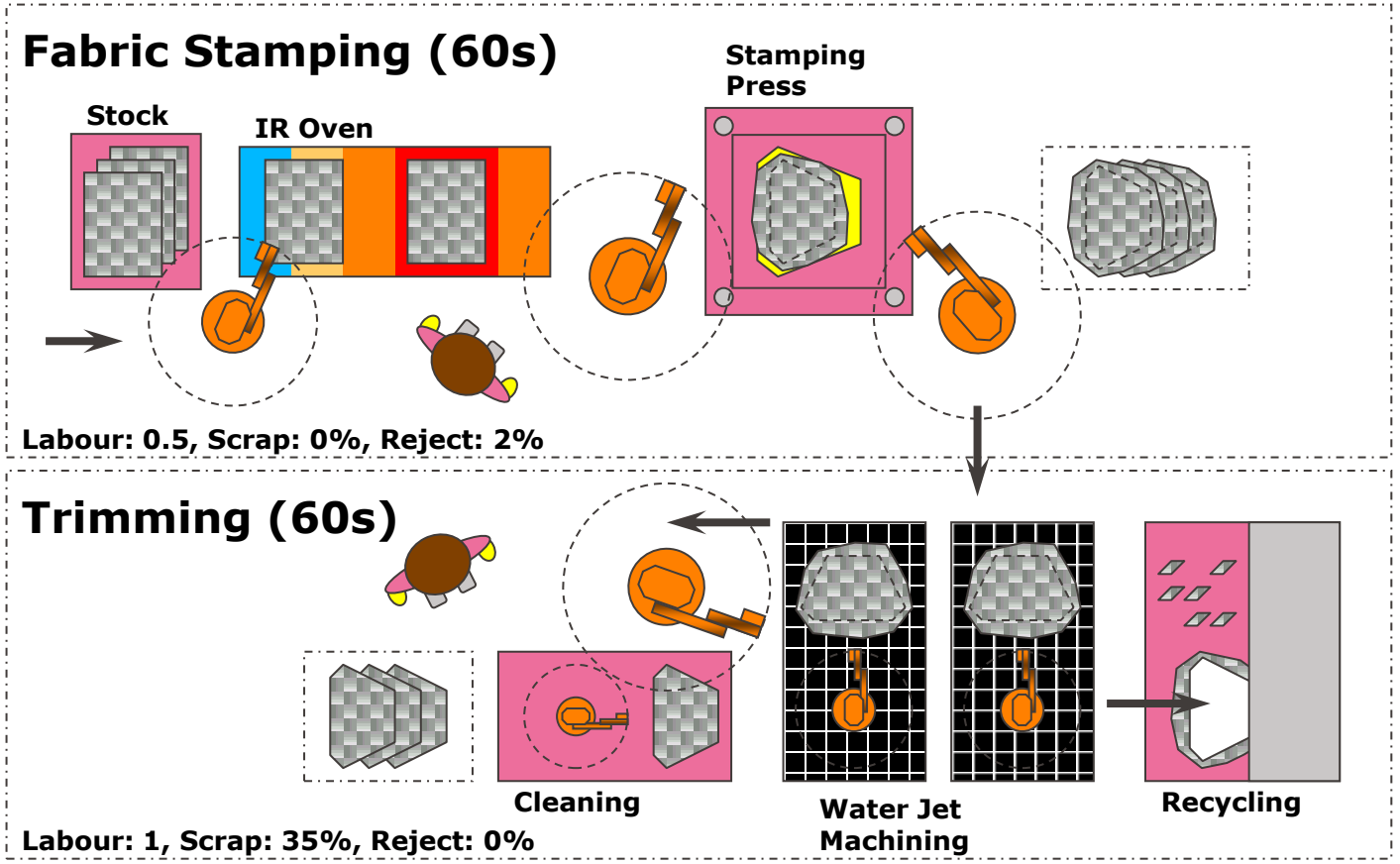
Example Process 3

- SMC Compression



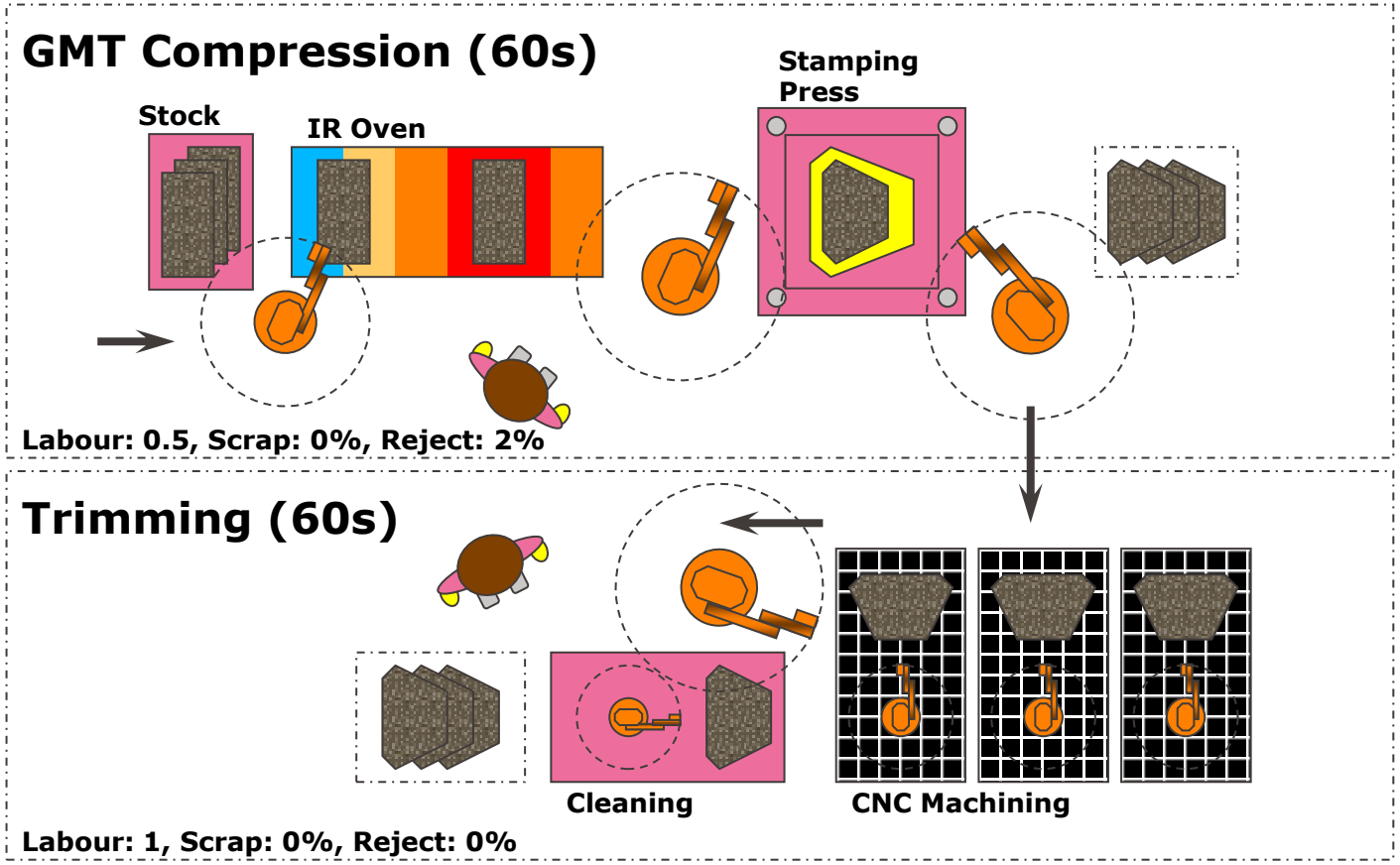
Example Process 4

- Thermoplastic Fabric Stamping



Example Process 5

- GMT Compression Molding



Equipment costs for exercise

- Machine costs

Item	*Cost €*	*Power kW*	*Area m²*	*Life*
Buffer	10,000	5	15	
Die Cast Machine	900,000	150	200	
Mg Die Casting Tool	200,000	-	-	250,000 shots
Robot	75,000	10	20	
Water Quench Buffer	20,000	5	15	
Hot Trim Punching	80,000	30	15	
Cold Trim Punching	80,000	30	15	
Punching Tool	20,000	-	-	500000 shots
CNC Trimming Station	300,000	50	20	
Manual Debur	10,000	5	10	
Preforming IR Oven	100,000	15	150	
Preforming Press	200,000	20	40	
Cutting Table	10,000	5	15	
RTM Injection Machine	150,000	20	15	
RTM Press	200,000	50	25	
RTM Tool	150,000	-	-	250,000 shots
Post Cure Oven	100,000	150	50	
Trimming Machine	200,000	20	20	
Robotic Cleaning Machine	100,000	10	20	
SMC Tool	200,000	-	-	1,000,000 shots
SMC Press	400,000	50	30	
Thermoplastic IR Oven	200,000	20	200	
Stamping Press	200,000	40	15	
Stamping Tool	100,000	-	-	1,000,000 shots
Water Jet Cutting	350,000	15	20	
Shredding	200,000	100	25	
Drilling	350,000	15	20	
GMT Tool	300,000	-	-	1,000,000 shots
Compression Press	900,000	50	150	

Annex 1: Cost tool arithmetic

Production Dashboard

- Production Dashboard

Material mass per part (kg)

Target production rate (p/yr)

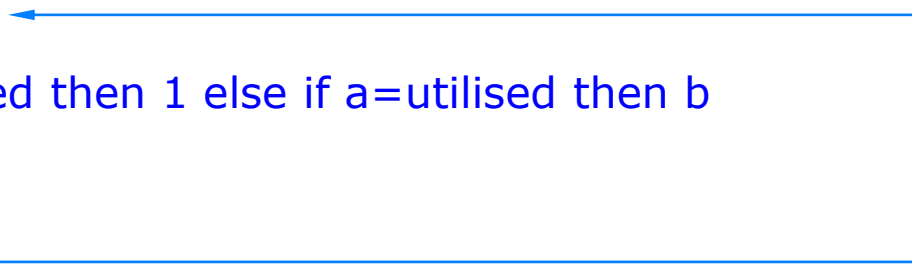
Production duration (yrs

Actual operational time (hrs/yr)

Effective utilisation (.) = if a=dedicated then 1 else if a=utilised then b

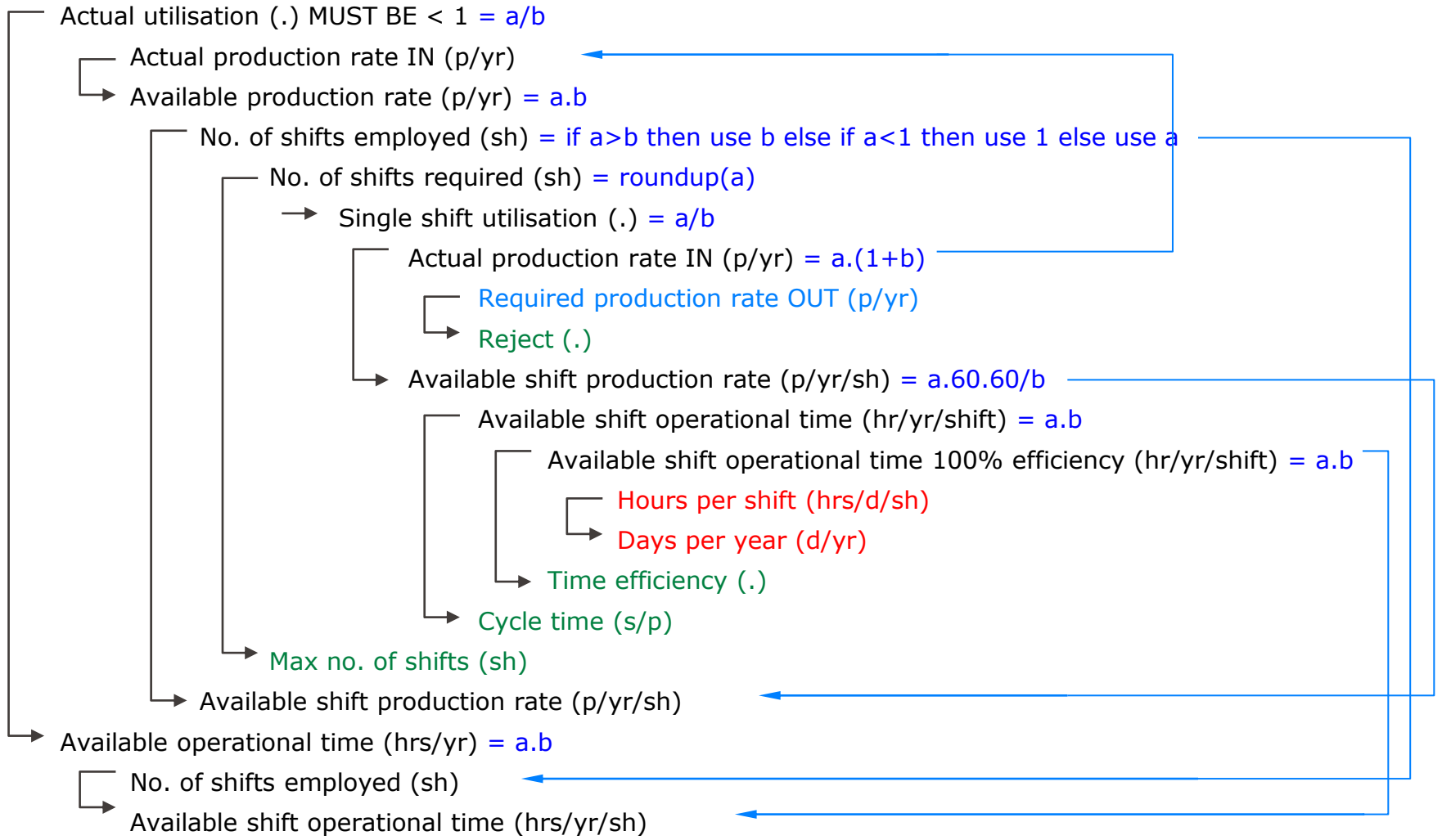
- Dedicated / Utilised
- Actual utilisation (.)

No. of direct labour (pns)



Production Dashboard

- Actual operational time (hrs/yr) = a.b



Cost Calculation

- Total Production Cost

Total Production Cost (€/p) = a+b+c+d+e+f+g

- Material cost
- Equipment cost
- Tooling cost
- Plant operating cost
- Energy cost
- Labour cost
- Consumables cost

Material Cost Calculation

- Material Cost

Material value IN (€/p) = a/b

- Annual material cost IN (€/yr) = a.b
  - Material cost (€/kg)
  - Material mass IN per year (kg/yr) = a.b
    - Actual production rate IN (p/yr) ←
    - Material mass per part IN (kg/p) = a.(1+b)
      - Material mass per part OUT (kg/p)
      - Scrap (.)
- Target production rate (p/yr) ←

Equipment Cost Calculation

- Equipment Cost

Machine depreciation (€/p) = a/b

- Process depreciation cost (€/yr) = a.b
  - Annual depreciation cost (€/yr) = a/b
    - Equipment capital cost (€)
    - Depreciation time (yrs) = if a=utilised then b else c
      - Dedicated / Utilised
      - Time until replacement (yrs)
      - Production duration (yrs)
  - Effective utilisation (.)
- Target Production rate (p/yr)

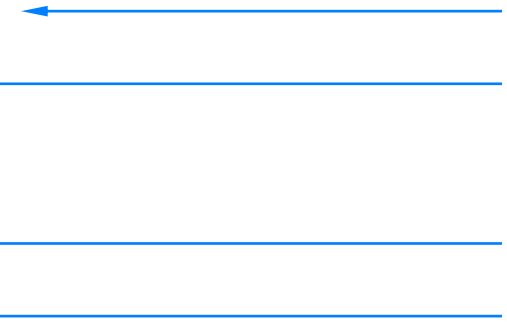
Wakeman

Tooling Cost Calculation

- Tooling Cost

Tool cost (€/p) = a/b

- Annual tool cost (€/yr) = a/b
  - Total tool cost (€) = a.b
    - Tool cost (€/tl)
    - No. of tools (tls) = roundup(a/b)
      - Total no of shots in process (shts) = a.b
        - Actual production rate IN (p/yr)
        - Production duration (yrs)
      - Tool life in shots (shts)
  - Production duration (yrs)
- Target production rate (p/yr)



Wakeman

Plant Operation Cost Calculation

- Plant Operation Cost

Plant operating cost (€/p) = a/b

- Annual plant operating cost (€/yr) = a.b
  - Full plant operating cost (€/yr) = a.b
    - Plant operating cost (€/m2/yr)
    - Plant area (m2)
  - Effective utilisation (.)
  - Target production rate (p/yr)

Wakeman

Energy Cost Calculation

- Energy Cost

Energy cost (€/p) = a/b

- Annual energy cost (€/yr) = a.b
  - Energy cost (€/hr) = a.b
    - Energy cost (€/kWh)
    - Machine power (kW)
  - Actual operational time (hrs/yr)
- Target production rate (p/yr)

Labor Cost Calculation

- Labor cost (€/p) = a+b

Direct labor cost (€/p) = a.b

Direct labor cost per person (€/p/pn) = a/b

Annual direct labor cost (€/yr) = a.b

Direct labor cost per person (€/hr)

Actual operational time (hrs/yr)

Target production rate (p/yr)

No. of direct persons (pns)

Indirect labor cost (€/p) = a.b

Indirect labor cost per person (€/p/pn) = a/b

Annual direct labor cost (€/yr) = a.b

Indirect labor cost per person (€/hr)

Actual operational time (hrs/yr)

Target production rate (p/yr)

No. of indirect persons (pns) = a.b

Direct / Indirect labor ratio (.)

No. of direct labor persons (pns)

Wakeman

Consumable Cost Calculation

- Consumable Cost

Consumables cost (€/p) = a.b

- No. of direct labour persons (pns)
- Consumables cost per person (€/p/pn) = a/b
  - Annual consumables cost (€/yr) = a.b
    - Consumables cost per direct labour person (€/hr)
      - Actual operational time (hrs/yr)
    - Target production rate (p/yr)

Annex 2: Historical data

- Use with caution

Raw material costs: polymers

Polymer	€/kg	Supplier
Polypropylene (PP)	0.7	Montell
Polyethylene terephthalate (PET)	3.5	DuPont
Polyamide 12 (PA12)	8.4	EMS
Polyphenylene sulfide (PPS), (40-50 for film)	5-13	GE plastics
Polyetherimide (PEI)	17.6-22	GE plastics
Polyetheretherketone (PEEK)	68-77	Victrex
Unsaturated polyester	1.1-6.6	Ashland
Vinylester	3.3-4.4	Dow Chemical
Epoxy	2.2-55	Shell
Phenolics	1.65-5	Budd
Cyanate Esters	62	Bryte
Polyurethanes	5.5-14	Dow
Bismaleimides (BMI)	78	ABR organics

Raw material costs: un-impregnated textiles

Reinforcement	€/kg	Supplier
Glass	**1.6**	**Vetrotex/Owens Corning**
Carbon (80k-12k)	**15-17.5**	**Fortafil/Tenax**
Kevlar	**23**	**DuPont**
GF weave (1200 tex, 300g/m^2)	**10**	**SP systems** (low volume)
aramid weave (300g/m^2)	**47**	
CF weave (HS 12k CF, 300g/m^2)	**78**	
CF weave (IM 12k CF, 300g/m^2)	**124**	
GF NCF (100" wide, 1000g/m^2)	**2.9-3.2**	**Saertex** (medium to high volume)
commercial 12k CF NCF (100" wide, 1000g/m^2)	**17-31**	
aerospace 12k CF NCF (100" wide, 1000g/m^2)	**44-47**	
GF biaxial braid	**11-15**	**A&P Technology**
CF biaxial braid, light areal weight	**90**	
CF biaxial braid (high volumes, automotive carbon at €15/kg)	**31**	

Semi-finished products: thermoplastic textile composites

Material form	€/kg	Supplier
CF/PA12 partially preconsolidated sheet	50 - 54	Schappe Techniques
GF/PA12 sheet	12.5 - 16.5	Lanxess / Bond Laminates (dependant on CF grade, thickness and volume)
CF/PA6.6 sheet	30 - 50	
GF/PA6 sheet	7.2 - 10.4	
GF/PET sheet	4.6 - 7.1	Vetrotex (Twintex)
GF/PP dry fabric	3 - 4.5	
GF/PP sheet	3.5 - 5.5	
GF/PP, GMT sheet	3.0	Quadrant Plastic Composites
GF/PP sheet, GMTex	3.5 - 5.5	
GF/PP UD tape	4.9 - 6.4	Plytron
PEI/GF sheet	60	CETEX consolidated sheet (Ten Cate)
PEI/CF sheet	140	
PPS/GF sheet	60	
PPS/CF sheet	140	
CF/PP tape	16 - 29	GuritSuprem/ Flex composites
CF/PA6 tape	19 - 30	
CF/PA12 tape	22 - 31	
CF/PET tape	19	

Semi-finished products: thermoset textile composites

Material form			€/kg	Supplier
GF/Epoxy	woven prepreg	720g/m^2, 1m x 50m roll	26	SP systems, also: Hexel, Cytec
CF/Epoxy	UD prepreg	476g/m^2 (CG carbon), 1m x 150m roll	29	
CF/Epoxy	UD prepreg	476g/m^2 (HS carbon), 1m x 150m roll	34	
CF/Epoxy	UD prepreg	476g/m^2 (HE carbon), 1m x 150m roll	37	
CF/Epoxy	UD prepreg	476g/m^2 (IM carbon), 1m x 150m roll	72	
CF/Epoxy	UD prepreg	461g/m^2 (HM carbon), 1m x 150m roll	91	
Aramid/epoxy	UD prepreg	545g/m^2, 1m x 150m roll	50	
CF/Epoxy	woven prepreg	(HS carbon), 517g/m^2,1m x 50m roll	59	
Closed cell	SAN core	5mm, 50kg/m^3	10/m^2	ATC Chemicals (SP systems)
Closed cell	SAN core	30mm, 50kg/m^3	41/m^2	

Typical composite processing equipment costs (1)

Equipment	Power [kW]	Area [m^2]	Cost [€]	Supplier/ contact	Cost / minute	Cost / part
Braiding machine	40	25m^2	€250-350k for 172 carriers (€1,5k/carrier)	Eurocarbon or A&P	€0.4	€0.67/m (600mm/ min)
Warp knitting machine (100")	25	500m^2	€1,500k	LIBA or Karl Mayer	€2.0	€6.7/m 0.3m/min
Hydraulic press	150	90m^2	1500 tonne = €900k (€50k-€60k/1000kN)	Dieffenbacher	€1.1	€1.1 (60s)
Injection moulding machine	480	90m^2	4000 tonne = €3,200k (€80k / 1000kN)	Battenfeld	€3.8	€5.7 (90s)
IR oven	80	20m^2	€150k (medium GMT type)	Tetas	€0.25	€0.25 (60s)
LFT machine	500	40m^2	€400k (e.g. 200k parts/yr)	Dieffenbacher	€0.92	€0.92 (60s)
Transfer robot	15	25m^2	€60k + fixture costs	ABB	€0.1	€0.1 (60s)
Reactive injection machine	20	10m^2	€400k (200 tonnes/year)	ATP	€0.43	€6.5 (15min)

Utilisation based, 3 shift pattern, 7 year production,
Including: plant area, energy costs, capital costs
Excluding: direct operators, in-direct overheads

Typical composite processing equipment costs (2)

Equipment	Power [kW]	Area [m^2]	Cost [€]	Supplier/ contact	Cost / minute	Cost / part
Preforming press	315kW	110m^2	€413k (floor pan)	Cannon	€0.83	
SRIM injection system	20kW	40m^2	€400k (4-8 litre lance, €200k for simpler system)	Cannon	€0.46	€2.3 (5min)
RTM press	100kW	70m^2	€680k (floor pan)	Cannon	€0.85	€12.8 (15min)
Oven	150kW	50m^2	€68k	many	€0.26	€15.6 (1hour)
Buffer	0	25m^2	€34k	custom	€0.06	€0.9 (15min)
RTM injection unit	20kW	15m^2	€170k (for floor pan; but production machines at €40k)	Dopag, Aplicator	€0.21	€3.25 (15min)
Finishing machine	5kW	100m^2	€204k (floor pan)	ABB, Staubli	€0.32	€19.2 (60min)
Autoclave, small	20kW	10m^2	€230k	Aeroform	€0.26	€62.4 (4 hours)
Autoclave, medium	e.g. 100kW	50m^2	€775k		€0.93	€223 (4 hours)
Autoclave, large	e.g. 800kW	150m^2	€1,400k		€2.32	€557 (4 hours)
Autoclave, v.large (11m x 36m)	10MW	396m^2	€31,000k		€41	€9840 (4 hours)
Automated tape laying (ATL)	80kW	150m^2	€5,000k (Airbus data)	Ingersol, Cincinnati	€5.3	€318 (1hour)
Automated fibre placement (AFP)	80kW	150m^2	€5,000k (Airbus data)		€5.3	€318 (1hour)

Utilisation based, 3 shift pattern, 7 year production, Including: plant area, energy costs, capital costs, Excluding: direct operators, in-direct overheads

Laboratory for Processing of Advanced Composites