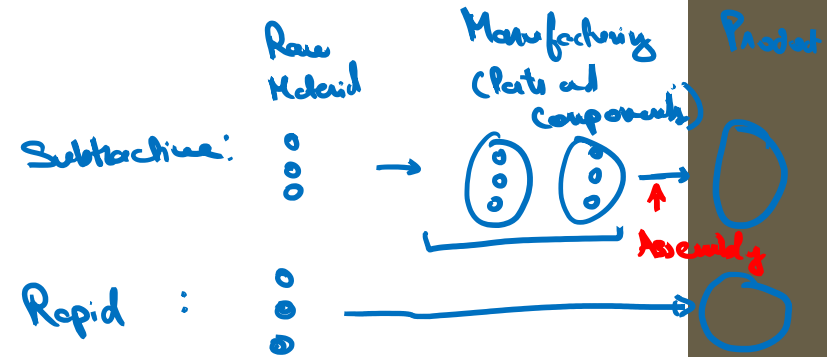


Product costing for Rapid Manufacturing

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- Life-Cycle Costing



Cost and price structure

Direct

Direct Labour Cost + Materials = Prime Cost/Operational Cost.

- Direct labour cost : cost of actual labour used to produce the product.
- Direct materials cost comprises the cost of raw or semi-finished materials that can be directly attributed to the product.

Factory Overhead + Prime Cost = Cost of Goods Manufactured / Manufacturing cost = *DM + DL + IM + IL + Miscellane*

- Overhead Cost:

Tools, fixtures, nuts and bolts

Indirect

- Indirect materials cost (factory supplies and lubricants), indirect labour costs (cost of supervision and inspection and the salaries of factory clerks), and fixed and miscellaneous costs such as rent, insurance, taxes, depreciation, maintenance and repair, utilities, and small tools.

Design and Manufacturing Costs

Manufacturing costs

- Manufacturing costs form the basis for determining the actual recurring cost of making a product.
- Manufacturing costs are generally the sum of the costs from four primary sources:
 1. **Recurring labour costs**:- Labour costs refer to the cost of the people required to perform specific activities. The labour cost per unit associated with an activity performed during manufacturing is determined from either

$$C_L = \frac{N_L T L_R}{N_p}$$

Handwritten annotations:
- N_L : No. of people
- T : Time
- L_R : labour rate
- N_p : No. of units

Design and Manufacturing Costs

$$TC = \underbrace{FC}_{\text{Capital Costs}} + \underbrace{VC}_{\text{Variable Costs}}$$

Manufacturing costs

2. Recurring material costs:- The cost of the materials associated with an activity is given by

$$\underline{C_M} = \underline{U_M} \underline{C_m}$$

where

- U_M = Quantity of the material consumed as indicated by its count, volume, area, or length
- C_m = Unit cost of the material per count, volume, area, or length

3. The allocation of nonrecurring tooling:-

- Tooling costs are nonrecurring costs associated with activities that occur only once or only a few times.
- Examples of tooling costs are programming and calibration costs for manufacturing equipment, and training of people.

Design and Manufacturing Costs

Manufacturing costs

Capital cost

- Capital costs are the costs of purchasing and maintaining the manufacturing equipment and facilities.

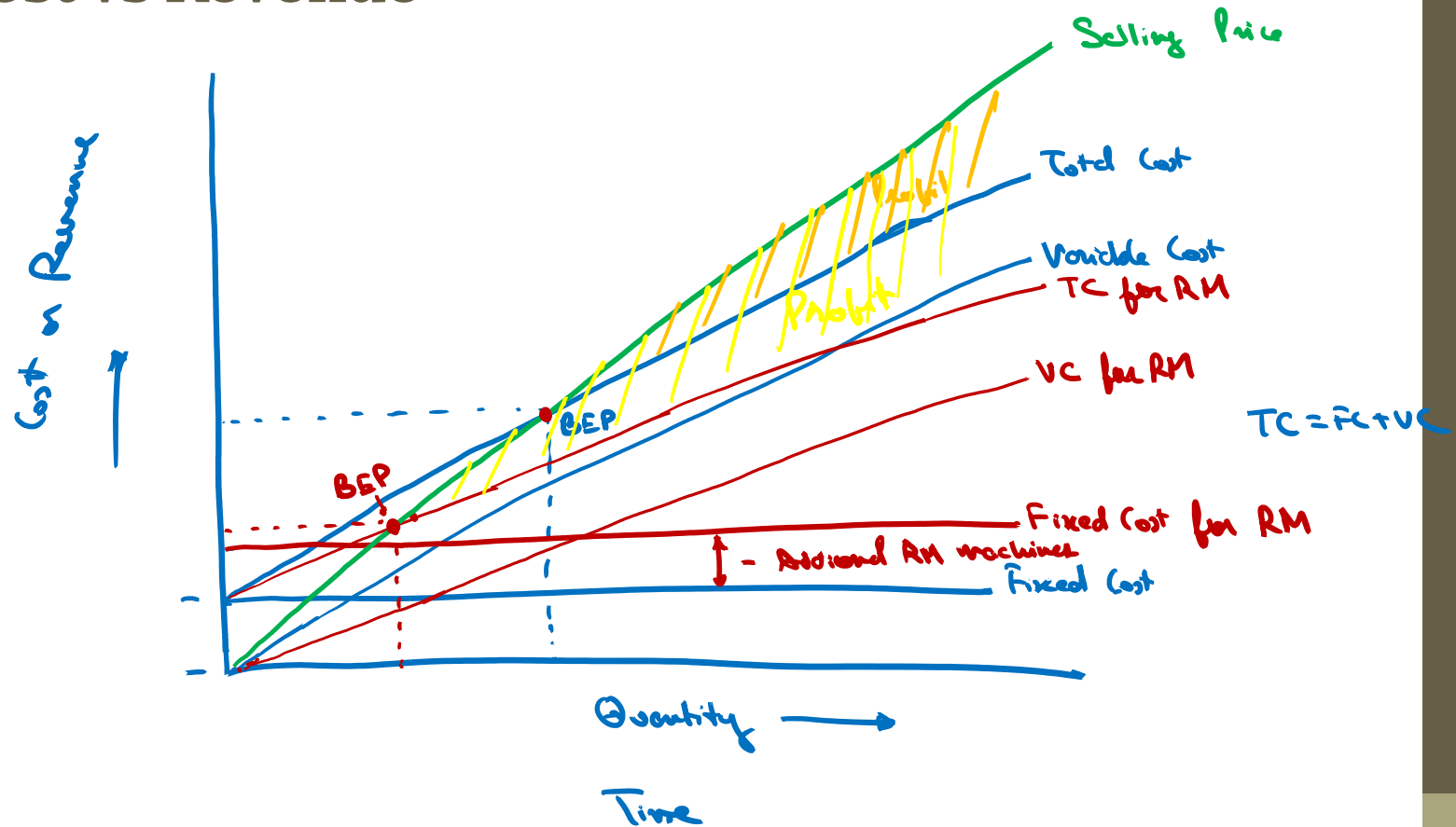
$$C_c = \frac{TC_e}{N_p T_{op} T_d}$$

where

- T = Length of time taken by the activity
- N_p = Number of units that can be treated simultaneously by the activity
- C_e = Purchase price of the capital equipment or facility *Machines, Tractor Land, Room, factory*
- T_{op} = Operational time of the equipment or facilities expressed as the number of hours per year
- T_d = Depreciation life in years

Rapid Manufacturing Costs

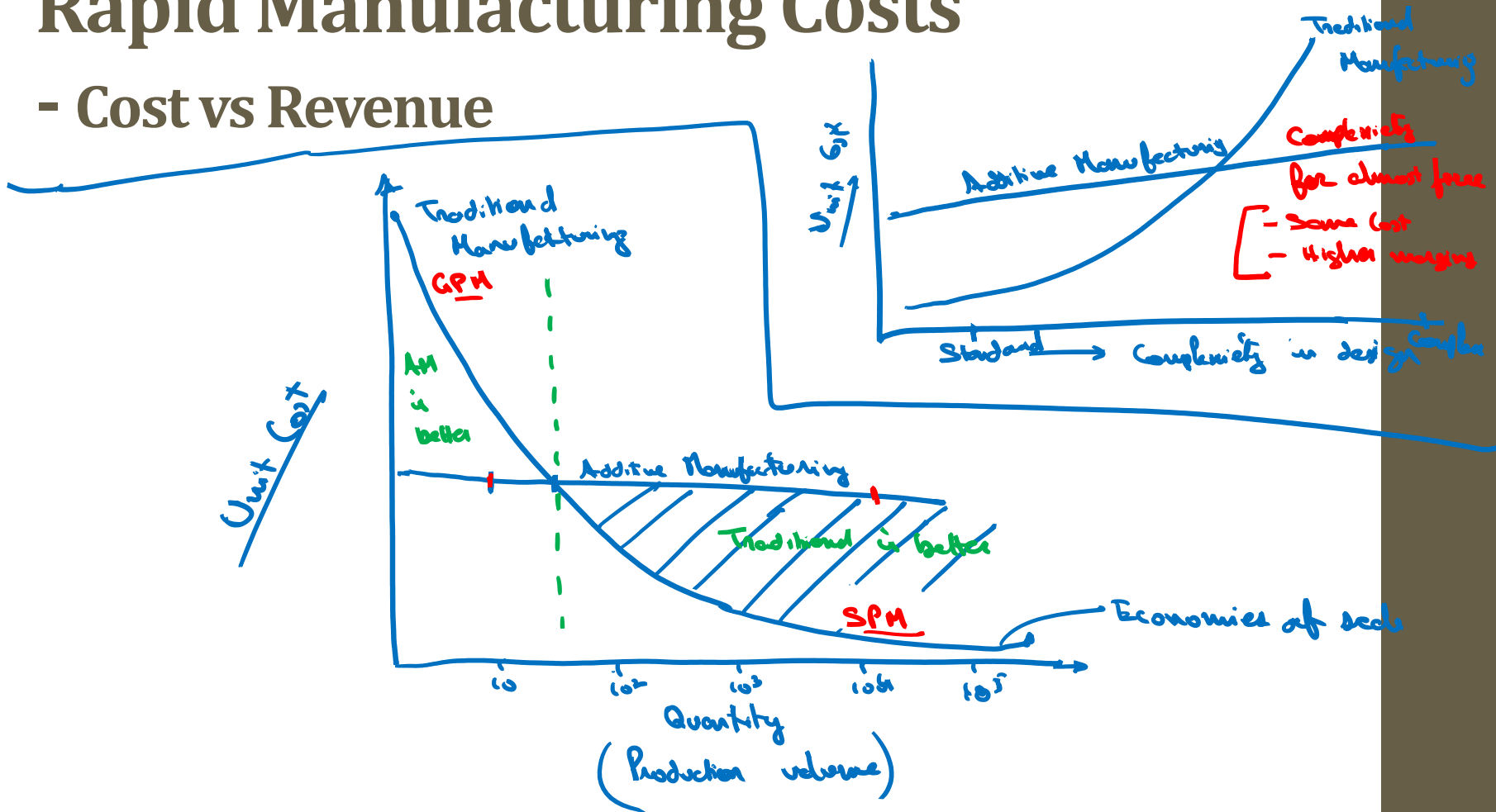
- Cost vs Revenue



BEP: Break
Even
Point

Rapid Manufacturing Costs

- Cost vs Revenue



Rapid Manufacturing Costs

- Machine costs

- Machine costs for Rapid Manufacture are largely dictated by machine depreciation.
- 1 Manufacturing capital equipment is normally depreciated using a straight line over 8–10 years (7–10 years in the USA) and so for Rapid Manufacture these rules apply, representing a significant departure from costing for RP, where depreciation is frequently applied over a shorter timescale, typically 5 years.
- Using an extended period for depreciation is valid so long as the equipment remains functional for that time period.
- This brings us on to the second factor of machine cost – maintenance.

2

Machine utilization

Rapid Manufacturing Costs

- Machine costs

Table: Approximate material costs for different processes

	<u>Process/material</u>	Cost per kg (\$)
Rapid <u>prototyping/</u> <u>manufacturing</u>	<u>Stereolithography/epoxy-based resin</u>	<u>175</u>
	Selective <u>laser sintering/nylon powder</u>	75
<u>Conventional manufacturing</u>	<u>Fused deposition modelling/ABS filament</u>	250
	<u>Injection moulding/ABS</u>	1.80
	<u>Machining/1112 screw-machine steel</u>	0.66

Rapid Manufacturing Costs

- Material costs

- These figures suggest that RM will struggle to compete with conventional processes where high material volumes through high product weight and/or high production volumes are involved.
- However, with the increased use of Rapid Manufacture (and to some extent ^{Calc} RP/T) larger volumes of material are being used and ultimately this should pave the way for lower material costs due to economies of scale.
- One of the perceived benefits of Rapid Manufacture is the potential to create products with zero waste — (negligible waste)
not actually

Rapid Manufacturing Costs

- Labour costs

- In general the labour costs associated with Rapid Manufacture are lower than those for machine and material costs.
- However, this aspect can vary due to the part size and complexity, manufacturing process used, degree of finishing required, production volumes and hourly labour costs.
- Labour costs bring up a number of discrepancies between costs for RP and costs for RM.

↑
Relatively
expensive

↑ Higher volume
(Lesser Labour cost)

Machine + Material + Labour
(50-75%) (20-40%) (5-30%)

Rapid Manufacturing Costs

- Cost estimation

Cost Model

- Broadly speaking, costs fall into four main categories:
 - machine purchase,
 - machine operation,
 - material, and
 - labor costs.
- In equation form, this high level cost model can be expressed, on a per build basis, as:

$$\text{Cost} = P' + O' + M' + L'$$

- or, on a per part basis, as

$$\text{cost} = p + o + m + l = \underline{1/N} \times (P + O + M + L)$$

$$\frac{P}{N} + \frac{O}{N} + \frac{M}{N} + \frac{L}{N}$$

Rapid Manufacturing Costs

- Cost estimation

Cost Model

- **Purchase price** for one build can be calculated as:

$$P = \frac{\text{PurchasePrice} \cdot T_b}{0.95 \cdot 24 \cdot 365 \cdot Y}$$

- where T_b is the time for the build in hours and $24 \cdot 365$ represents the number of hours in a year.

Operation cost is simply the build time multiplied by the cost rate of the machine, which can be a complicated function of

- machine maintenance,
- utility costs,
- cost of factory floor space, and
- company overhead,

$$O = T_b \cdot C_o$$

Build Time (above T_b) and *Cost/Time* (above C_o) are handwritten annotations.

- where the operation cost rate is denoted by C_o .

Rapid Manufacturing Costs

- Cost estimation

Cost Model

- **Material cost** has a complex dependency on the recyclability of the material used. For instance, for powder processes where the build material is not 100% recyclable, the fraction of the build volume made up of parts versus loose powder; and/or the powder capture efficiency of the process.

$$M = k_s \cdot k_r \cdot N \cdot v \cdot C_m \cdot \rho$$

Support *Recyclability* *no. of units* *Volume* *cost / mass* *mass density*

- The term k_r will be introduced, for the purpose of modeling the additional material consumption that considers these factors. *100% consumption?*
- In addition, for processes that require support materials (such as FDM and SL), the volume and cost of the supports needed to create each part must also be taken into account. *(Recyclability)*
- The factor k_s takes this into account for such processes; typical values would range from 1.1 to 1.5 to include the extra material volume needed for supports. *10% 50%*

Rapid Manufacturing Costs

- Cost estimation

Cost Model

- **Labor cost** is the time required for workers to:

- Pre processing*
- set up the build,
- Post processing*
- remove fabricated parts,
 - clean the parts,
 - clean the machine, and
 - get the machine ready for the next build.

$$L = \underline{T_1} \cdot \underline{C_1}$$

Rapid Manufacturing Costs

- Cost estimation

Build Time Model

- The major variable in this cost model is the build time of the parts.
- Build time (T_b) is a function of part size, part shape, number of parts in the build, and the machine's build speed.
- Viewed slightly differently, build time is the sum of scan or deposition time (T_s), recoat time (T_r), and delay time (T_e):

$$\underline{\underline{T_b}} = \underline{\underline{T_s}} + \underline{\underline{T_r}} + \underline{\underline{T_e}}$$

- For this analysis, we will assume that we are given the part size in terms of its volume, v , and its bounding box, aligned with the coordinate axes: $\underline{\underline{bb_x}}$, $\underline{\underline{bb_y}}$, $\underline{\underline{bb_z}}$.
- Recoat time is the easiest to deal with.

Rapid Manufacturing Costs

- Cost estimation

Build Time Model

- The processes that build in material beds or vats have to recoat or deposit more material between layers; other processes do not need to recoat and have a T_r of 0.
- Recoat times for building support structures can be different than times for recoating when building parts, as indicated by.

$$T_r = \underbrace{L_s \cdot T_{rs}}_{\text{Support}} + \underbrace{L_p \cdot T_{rp}}_{\text{Part}}$$

- where L_s is the number of layers of support structure,
- T_{rs} is the time to recoat a layer of support structures,
- L_p is the number of layers for building parts (L_p is bb_z/L_T),
↳ layer thickness
- T_{rp} is the recoat time for a part layer, and
- L_T is the layer thickness.

Rapid Manufacturing Costs

- Cost estimation

Build Time Model

- Scan/deposition time is a function of the total cross-sectional area for each layer, the scan or fill strategy utilized, and the number of layers.
- Cross-sectional area depends upon the part volume and the number of parts.
- Scan/deposition time also depends upon whether the machine has to scan vectors to build the part in a pointwise fashion, as in SL, SLS, FDM, or the part deposits material in a wide, line-wise swath, as in ink-jet printing processes, or as a complete layer, as in layer-based photopolymerization processes.
- The equations are similar; we will present the build time model for scanning and leave the wide swath deposition and layer-based scanning processes for the exercises.

Rapid Manufacturing Costs

- Cost estimation

Build Time Model

- The number of parts on the platform can be computed as:

$$N = \underbrace{\left(\frac{PL_x + g_x - \underline{20}}{\underline{bb}_x + g_x} \right)}_X \underbrace{\left(\frac{PL_y + g_y - \underline{20}}{\underline{bb}_y + g_y} \right)}_Y$$

Distance from edges (pointing to the 20 in the numerator)

- where PL_x , PL_y are the platform sizes in X and Y, g_x , g_y are the X and Y gaps, and the 20 mm terms prevent parts from being built at the edges of the platform (10 mm buffer area along each platform edge).
- This analysis can be extended to 3D build chambers for processes which enable stacking in the z direction.

Rapid Manufacturing Costs

$$T = \underbrace{T_h} + \underbrace{T_s} + \underbrace{T_e}$$

- Cost estimation

Build Time Model

- The term, T_s , is a function of scan speed and scan length.

Scan time or Deposition time

$$T_s = \frac{N \cdot sl}{3,600 \cdot ss_{avg}}$$

Scan length $\approx f(A_{avg})$ (Average Cross-sectional area)

Average Scan Speed $\approx f(SS_x, SS_y)$

hours into seconds

Rapid Manufacturing Costs

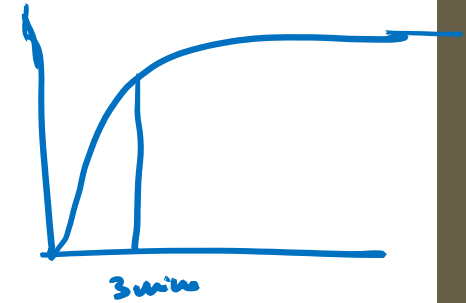
- Cost estimation

Build Time Model

- The final term in the build time is the delay time, T_e .
- Many processes have delays built into their operations, such as:
 - platform move time,
 - pre-recoat delay ($T_{predelay}$),
 - post-recoat delay ($T_{postdelay}$),
 - nozzle cleaning,
 - sensor recalibration,
 - temperature setpoint delays (waiting for the layer to heat or cool to within a specified range), and more.
- These delays are often user specified and depend upon build details for a particular process.

Rapid Manufacturing Costs

- Cost estimation



Build Time Model

- Additionally, some processes require a start-up time, for example, to heat the build chamber or warm up a laser.
- This start-up time will be denoted T_{start} . For our purposes, delays will be given by, but it is important to realize that each process and machine may have additional or different delay terms.

$$T_e = L_p (T_{\text{predelay}} + T_{\text{postdelay}}) + T_{\text{start}}$$

↑
No. of
layers

Five features $\Rightarrow$ Longer pre-coat delays
- resin to cure
- strengthen the parts

Rapid Manufacturing Costs

- Life-Cycle Costing

- In addition to part costs, it is important to consider the costs incurred over the lifetime of the part, from both the customer's and the supplier's perspectives.
- For any manufactured part (not necessarily using AM processes), life-cycle costs associated with a part can be broken down into six main categories:

1. equipment cost,
 2. material cost,
 3. operation cost,
 4. tooling cost,
 5. service cost, and
 6. retirement cost.
- Replacement cost
Salvage value

Actual manufacturing

Total Cost of Ownership

$$LCC = P + O - S$$

↑ ↑
Material Resale price
labour Service

To recapitulate:

- What do you understand by cost and price structure?
- How to estimate design and manufacturing costs?
- Explain in brief about cost estimation.
- How to determine life-cycle costing?

Thanks