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3 Mold Cost Estimation

3.1 The Mold Quoting Process

The quoting process for plastic parts can be difficult for both the mold customer and supplier. Consider the view of the mold customer. The procurement specialist for the product development team sends out requests for quotes (RFQs) to several mold makers. After waiting days or weeks, the quotes come back and the customer discovers that the development time and cost of the mold may vary by a factor of 3 or more. In such a case, prospective mold purchasers should ask about the details of the provided quotes, and check if the costs can be reduced through product redesign. To reduce uncertainty related to pricing and capability, many prospective customers maintain a list of qualified suppliers, who tend to provide faster turn-around, more uniform quality, and better pricing across multiple projects. Long-term, trusting partnerships can provide for rapid application and mold development by avoiding the quoting process altogether and invoicing on a labor cost plus materials cost (referred to as "cost plus") basis.

Now consider the view of the mold supplier. The mold designer must invest significant time developing a quote that may have a relatively small chance of being accepted. Sometimes, the mold designer may have to redesign the product and perform extensive analysis to provide the quote. While the quote may seem high to the prospective customer, the design may correspond to a mold of higher quality materials and workmanship that can provide a higher production rate and longer working life than some other lower cost mold. This more expensive mold may quickly recoup its added costs during production.

From time to time, mold-makers and molders will adjust their quote based on whether or not they want the business. If the supplier is extremely busy or idle, then the estimated number of hours and/or hourly rate may be adjusted to either entice or to discourage the potential customer from accepting the quote. Such adjustments should be avoided since the provided quote does not represent the true costs of the supplier, which would become the basis in a long term and mutually beneficial partnership between the mold supplier and the customer.

The provided quote typically provides payment and delivery terms for the mold(s) and perhaps even the molded part(s). A typical mold purchase agreement may specify that the cost of a mold is paid in three installments:

- the first third: on acceptance of the quote (after which the mold base and key materials are typically purchased);
- the second third: half-way through the mold making project (often when cavity inserts have been machined); and
- the final third: upon acceptance of the quality of the molded parts.



Figure 3.1: Schedule of mold and molding expenses

After the mold is purchased, molds are typically shipped to the specified molder or the customer's facility where the parts are molded and marginal costs are incurred on a per part basis. The cash outlays for a typical project are plotted in Figure 3.1 on a monthly basis. The material and processing costs in month 3 are related to molding trials to validate and improve the mold design; a hundred or so pre-production parts may be sampled at this time for marketing and testing purposes. Later, monthly costs are incurred related to production. Maintenance costs may appear intermittently throughout production to maintain the quality of the mold and moldings.

There has been a trend in the industry towards large, vertically integrated molders with tightly integrated supply chains who can supply molded parts (and even complete product assemblies). As such, the structure of the quote can vary substantially with the structure of the business. With a vertically integrated supplier, there is typically an up-front fee for the costs associated with the development of the mold, followed by a fee for each molded part. To protect the supplier, contracts are typically developed that specify minimum production quantities with discounts and/or fees related to changes in the production schedule.

Since the structure and magnitude of quotes will vary substantially by supplier(s), a prospective buyer of plastic parts should solicit quotes from multiple vendors and select the quote from the supplier that provides the most preferable combination of molded part quality, payment terms, delivery terms, and service.

3.2 Cost Drivers for Molded Parts

There are three main drivers of the cost of a molded part:

- the cost of the mold and its maintenance,
- the materials cost, and
- the processing cost.

Figure 3.2 provides a breakdown of these primary cost drivers and their underlying components. It is important to note that these costs do not include indirect costs such as overhead or profits. However, such indirect costs may be accounted through the adjustment of hourly rates and other costs.



Figure 3.2: Cost drivers for a commodity and specialty part



Figure 3.3: Cost drivers for a commodity and specialty part

Even though most molded products have the same cost drivers, the proportion of costs varies widely by application. Figure 3.3 shows the cost breakdown for a commodity application (such as a cable tie with a production volume of 10 million pieces) and a specialty application (such as a custom electrical connector with a production volume of 100,000 pieces). While these two products are approximately the same weight, it is observed that the magnitude and proportion of costs are vastly different.

3.2.1 Effect of Production Quantity

Minimization of the total molded part cost is not a simple task since injection molds and molding processes are optimally designed for different target production quantities. Typically, there is a trade off between the upfront investment in the mold and later potential savings related to the processing and material costs per part. Consider the data provided in Table 3.1 for a molding application with production quantities of 50,000 and 5,000,000 pieces. As indicated, the lower production quantity may be satisfied with a two cavity, cold runner mold. By comparison, the mold design for the higher production quantity utilizes a hot runner system allowing the simultaneous molding of 32 cavities with a lower cycle time and reduced material consumption.

In theory, the production quantities should be known beforehand and used to design an "optimal" mold for the specified quantity. In reality, the production schedules and quantities are not precisely known, so the molder and customer must carefully consider the possible result of using molds that are over or under designed. For this reason, break-even analysis should be utilized to consider the sensitivity of different mold designs to the total molded part cost.

Production quantity	50,000	5,000,000
Number of mold cavities	2	32
Runner system	Cold runner	Hot runner
Mold cost	\$10,000	\$250,000
Cycle time	30 s	20 s
Effective cycle time/part	15 s	0.6 s
Processing cost/part	\$0.40	\$0.04
Mold cost/part	\$0.20	\$0.05
Material cost/part	\$0.15	\$0.12
Total cost/part	\$0.75	\$0.21

3.2.2 Break-Even Analysis

Break-even analysis should be applied to ensure the design an appropriate mold. Consider the previous case for the two molds described in Table 3.1. It is useful to consider the total costs incurred to produce a given quantity. The total costs, C_{total} , may be computed as:

$$C_{\text{total}} = C_{\text{fixed}} + n_{\text{total}} \cdot C_{\text{marginal}}$$
(3.1)

where C_{fixed} is the total cost of the mold and its maintenance, n_{total} is the total production quantity across the life of the mold, and C_{marginal} is the total marginal cost of the resin, machine, labor, and energy on a per part basis. For a given mold design, the marginal cost per piece will remain fairly constant across the life of the application (though there may be cost decreases related to elimination of defects, reductions in cycle times, etc. as well as cost increases due to material pricing or shipping costs). To provide the best possible mold design and quote, multiple mold designs should be developed for different target production quantities, and the total production costs estimated and compared via break-even analysis.

Example: Consider the cost data provided in Table 3.1. Calculate the production volume where a hot runner mold becomes more economical than a cold runner mold.

Equation (3.1) is used to calculate the costs with the cold runner and hot runner as:

$$C_{\text{total}}^{\text{cold}_\text{runner}} = C_{\text{fixed}}^{\text{cold}_\text{runner}} + n_{\text{total}} \cdot C_{\text{marginal}}^{\text{cold}_\text{runner}}$$
$$C_{\text{total}}^{\text{hot}_\text{runner}} = C_{\text{fixed}}^{\text{hot}_\text{runner}} + n_{\text{total}} \cdot C_{\text{marginal}}^{\text{hot}_\text{runner}}$$

Equating these two costs and solving for the production volume provides the break-even quantity:

$$n_{\text{total}}^{\text{breakeven}} = \frac{C_{\text{fixed}}^{\text{hot_runner}} - C_{\text{fixed}}^{\text{cold_runner}}}{C_{\text{marginal}}^{\text{cold_runner}} - C_{\text{marginal}}^{\text{hot_runner}}}$$

The analysis assumes that the marginal cost per molded part consists primarily of the processing and material costs. Then, the marginal costs for the cold and hot runners are \$0.55 and \$0.16, respectively. Substituting these values provides:

 $n_{\text{total}}^{\text{breakeven}} = \frac{\$250,000 - \$10,000}{\$0.55/\text{part} - \$0.16/\text{part}} = \frac{\$240,000}{\$0.39/\text{part}} = 615,000 \text{ parts}$

The costs for the cold and hot runner mold designs are provided in Figure 3.4. While the cost function of Eq. (3.1) is linear, a log-log scale has been used in the figure to provide better resolution of the cost across a wide range of production volumes. In this example, the total cost for the 2 cavity cold runner mold and the 32 cavity hot runner mold are plotted as a function of the "realized" production quantity, *Q*. For this example, the 2 cavity cold runner mold cost up to the 615,000 part quantity, after which the 32 cavity hot runner mold provides a lower total cost.



Figure 3.4: Break-even analysis

The cost analysis will typically indicate the need for different mold designs at extremely low and extremely high production quantities. In the previous example, the upfront cost of the 32 cavity hot runner system can not be justified at low or moderate production quantities. At very high production quantities, however, a hot runner system is essential to maximizing profitability since the marginal costs of operating the hot runner mold are significantly less than those of the cold runner mold. While the breakeven analysis supports clear design decisions at very low and very high production quantities, the mold design can be less certain at intermediate production volumes. If the production quantity is on the order of 500,000 parts, then the best mold design may utilize neither 2 nor 32 cavities for this application, but rather an intermediate quantity of 4, 8, or 16 cavities with or without a hot runner. As such, multiple designs and cost estimates should be developed until a good balance is achieved between higher upfront investment and lower marginal costs. If necessary, the customer can be given more than one design to select the design that they think will ultimately be best.

Many molders and customers require a quick return on investment, and so will examine the total cost curve to accept the use of a hot runner system with high cavitation only if a desirably short payback period can be achieved. Sometimes, however, mold design decisions are not based solely on economics but rather by other concerns such as:

- The need for a mold to permit rapid color changes, for which a hot runner feed system may not be desirable. The color change issue in hot runners will be revisited in Section 6.4.8.
- The capability and preference of the molder that will use the mold. If the molder does not have the experience or auxiliaries required to utilize a hot runner system, then a cold runner mold may best be utilized.

• The lean manufacturing strategies of the molders to reduce costs and improve quality. For instance, it is not uncommon for molders to standardize on a specific type and size of mold to maximize production flexibility and reduce setup times.

As a general practice, the mold should be designed to maximize the molder's capability unless the application requirements and cost constraints dictate otherwise. When an advanced molding application has special requirements, it may be critical to select a molder with a specialized set of molding capabilities and standard operating procedures. Chapter 13 provides a survey of mold technologies, many of which require special molder capabilities.

3.3 Mold Cost Estimation

Many cost estimation methods have been developed for molded plastic parts with varying degrees of causality and accuracy [10–21]. The following cost estimation method was developed to include the main effects of the part design and molding process while being relatively simple to use. To use the developed method, the practitioner can refer to the cost data provided in Appendices A, B, and D, or provide more application specific data as available.

The total mold cost, $C_{\text{total_mold}}$, is the sum of the cost of all cavities, C_{cavities} , and the cost of the mold base, $C_{\text{mold base}}$, and the cost of the mold customization, $C_{\text{customization}}$:

$$C_{\text{total_mold}} = C_{\text{cavities}} + C_{\text{mold_base}} + C_{\text{customization}}$$
(3.2)

Mold maintenance costs are included as a portion of the mold amortization, and are calculated with the part cost. To demonstrate the cost estimation method, each of these cost drivers is analyzed for the laptop bezel shown in Figure 3.5. The example analysis assumes that 1,000,000 parts are to be molded of ABS from a single cavity, hot runner mold. The relevant application data required to perform the cost estimation is provided in Table 3.2.



Figure 3.5: Isometric view of laptop bezel

Parameter	Laptop bezel
Material	ABS
Production quantity	1,000,000
$L_{\rm part}$	240 mm
W _{part}	160 mm
H_{part}	10 mm
$A_{\text{part_surface}}$	45,700 mm ²
V _{part}	27,500 mm ³
$H_{ m wall}$	1.5 mm

Table 3.2: Laptop design data

Example: Estimate the total cost of a single cavity, hot runner mold for producing the laptop bezel. This example corresponds to the mold design shown in Figure 1.8.

Subsequent analysis will show that the cost of the core and cavity inserts are \$27,900, the cost of the mold base is \$3,700, and the cost of the customizations including the purchase of all associated components is \$43,200. As such, the estimated total cost the mold is:

 $C_{\text{total_mold}} = C_{\text{cavities}} + C_{\text{mold_base}} + C_{\text{customization}}$ $= \$27,900 + \$3,700 + \$43,200 \approx \$74,800$

3.3.1 Cavity Cost Estimation

The cost of the core and cavity inserts is typically the single largest driver of the total mold cost. The reason for their expense is that they need to contain every geometric detail of the molded part, be made of very hard materials, and be finished to a high degree of accuracy and quality.

The total cost of all the cavity and core inserts is driven by the cost of each set of inserts, C_{cavity} , multiplied by the number of cavity sets, n_{cavities} , and a discount factor, f_{cavity} -discount:

$$C_{\text{cavities}} = (C_{\text{cavity}} \cdot n_{\text{cavities}}) \cdot f_{\text{cavity_discount}}$$
(3.3)

Example: Estimate the total cost of all core and cavity insert sets for the laptop bezel. Since there is only one cavity and no cavity discount, the cost of all inserts sets is:

$$C_{\text{cavities}} = (\$27,900 \cdot 1) \cdot 1 = \$27,900$$

3.3.1.1 Cavity Set Cost

The cost of each cavity set is estimated as the sum of the materials costs, $C_{\text{cavity_material}}$, the insert machining costs, $C_{\text{cavity_material}}$, and the insert finishing costs, $C_{\text{cavity_finishing}}$.

 $C_{\text{cavity}} = C_{\text{cavity_material}} + C_{\text{cavity_machining}} + C_{\text{cavity_finishing}}$ (3.4)

Example: Estimate the cost of one set of core and cavity inserts for the laptop bezel.

Subsequent analysis will show that the cost of the materials is \$435, the cost of the cavity machining is \$25,800, and the cost of the cavity finishing is \$1,700. As such, the total cost for one core and cavity set is:

$$C_{\text{cavity}} = \$435 + \$25,800 + \$1,700 \approx \$27,900$$

3.3.1.2 Cavity Materials Cost

The cost of the cavity insert materials is the simplest and least significant term to evaluate. Specifically, the cavity materials cost is the volume of the cavity set, $V_{\text{cavity_material}}$, multiplied by the density, $\rho_{\text{cavity_material}}$, and the cost of the material per kilogram, $\kappa_{\text{cavity_material}}$:

$$C_{\text{cavity}_material} = V_{\text{cavity}_material} \cdot \rho_{\text{cavity}_material} \cdot \kappa_{\text{cavity}_material}$$
(3.5)

Cost data for some common metals are provided in Appendix B.

The cavity insert volume is the product of the cavity length, L_{cavity} the cavity width, W_{cavity} and the cavity height, H_{cavity} :

$$V_{\text{cavity material}} = L_{\text{cavity}} \cdot W_{\text{cavity}} \cdot H_{\text{cavity}}$$
(3.6)

The size of the cavity set is finalized during the mold layout design process as discussed in Chapter 4. From generalization of the later analysis, these dimensions can be roughly estimated as a function of the part size as follows:

$$L_{\text{cavity}} = L_{\text{part}} + \max \left[0.1 \cdot L_{\text{part}}, H_{\text{part}} \right]$$

$$W_{\text{cavity}} = W_{\text{part}} + \max \left[0.1 \cdot W_{\text{part}}, H_{\text{part}} \right]$$

$$H_{\text{cavity}} = \max \left[0.057, 2 H_{\text{part}} \right]$$
(3.7)

It should be noted that for the formula to work with the data provided in the Appendices, all dimensions must be stated in meters or converted with the data to another consistent set of units. As previously suggested, the analysis should be conducted using application specific data for the material properties, part geometry, mold geometry, or manufacturing processes when such data is available.

Example: Estimate the cost of the core and cavity insert materials for the laptop bezel. First, the dimensions of the core and cavity inserts are estimated. From the dimensions provided in Table 3.2, the preliminary dimensions of the inserts are:

$$\begin{split} L_{\text{cavity}} &= 0.24 \text{ m} + \max\left[0.1 \cdot 0.24 \text{ m}, 0.01 \text{ m}\right] = 0.268 \text{ m} \\ W_{\text{cavity}} &= 0.16 \text{ m} + \max\left[0.1 \cdot 0.16 \text{ m}, 0.01 \text{ m}\right] = 0.176 \text{ m} \\ H_{\text{cavity}} &= \max\left[0.057, 2 \cdot 0.01 \text{ m}\right] = 0.057 \text{ m} \end{split}$$

which provides a volume of:

 $V_{\text{cavity}_material} = 0.264 \text{ m} \cdot 0.176 \text{ m} \cdot 0.057 \text{ m} = 2.65 \cdot 10^{-3} \text{ m}^3$

To calculate the cost of the core and cavity insert materials, the type of material must be known. Since this is a tight tolerance part with a high production quantity, tool steel D2 is selected for its wear and abrasion resistance. This material has a density of 7670 kg/m³ and a cost of 21.4 \$/kg, which leads to a cost for the core and cavity insert materials of:

$$C_{\text{cavity}_{\text{material}}} = 2.65 \cdot 10^{-3} \text{ m}^3 \cdot 7670 \frac{\text{kg}}{\text{m}^3} \cdot 21.4 \frac{\$}{\text{kg}} = \$435$$

3.3.1.3 Cavity Machining Cost

The cavity machining cost, $C_{\text{cavity}_machining}$ is the single most significant driver of the total mold cost, and is a function of many variables including

- the volume and geometric complexity of the part to be molded,
- · the core and cavity inserts' material properties,
- the machining processes,
- the labor cost, and
- the quality of the inserts required.

The approach used here is to estimate the cavity machining cost by multiplying the machining time, $t_{\text{cavity machining}}$, with the machining labor rate, $R_{\text{machining rate}}$:

$$C_{\text{cavity}_machining} = t_{\text{cavity}_machining} \cdot R_{\text{machining}_rate}$$
(3.8)

The machining labor rate, $R_{machining_rate}$, varies substantially with the cost of living in the location where the mold is manufactured. A mold maker in a high cost of living area (such as Germany) will tend to have a higher labor cost than a mold maker in a low cost of living area (such as Taiwan). Furthermore, the labor rate will also vary with the toolset, capability, and plant utilization of the mold maker. For example, a mold maker using a 5 axis numerically controlled milling machine will tend to have more capability and charge more than a mold maker using manually operated 3 axis milling machines. Some approximate cost and efficiency

data for machining and labor rates are provided in Appendix D, though application specific data with the negotiated machinist's rate should be used if this data is available.

The cavity machining time is driven by the size and complexity of the cavity details to be machined, as well as the speed of the machining processes used. In theory, the exact order and timing of the manufacturing processes can be planned to provide a precise time estimate. In practice, however, this approach is fairly difficult unless the entire job can be automatically processed, for instance, on a numerically controlled mill.¹

The cavity machining time is estimated as the sum of the volume machining time, $t_{\text{cavity_volume}}$, and the area machining time, $t_{\text{cavity_area}}$. To take application specific requirements into account, the cavity machining time is then multiplied by a complexity factor, $f_{\text{cavity_complexity}}$ to consider geometric complexity as well as a machining factor, $f_{\text{machining}}$, then divided by an efficiency factor, $f_{\text{machining_efficiency}}$:

$$t_{\text{cavity_machining}} = \left(\frac{t_{\text{cavity_volume}} + t_{\text{cavity_area}}}{f_{\text{machining_efficiency}}}\right) \cdot f_{\text{cavity_complexity}} \cdot f_{\text{machining}}$$
(3.9)

The cavity volume machining time is a function of the volume of material to be removed and the material removal rate. To provide an approximate but conservative estimate, the assumption is made that the removal volume is equal to the entire volume of the core and cavity inserts. This may seem an overly conservative estimate, but in fact much of the volume must be removed around the outside of the core insert and the inside of the cavity insert.

The material removal rate is a function of the processes that are used, the finish and tolerances required, as well as the properties of the mold core and cavity insert materials. To simplify the analysis, a geometric complexity factor will later be used to capture the effect of different machining processes and tolerances needed to produce the required cavity details. As such, the volume machining time captures only the time to require the material removal as follows:

$$t_{\text{cavity_volume}} = \frac{V_{\text{cavity_material}}}{R_{\text{material_volume}}}$$
(3.10)

where $R_{\text{material_volume}}$ is the volumetric mold material removal rate measured in cubic meters per hour. Machining data for different materials are provided in Appendix B, though application specific material removal rates can be substituted if the depth of cut, speed, and feed rates are known [22].

¹ Prototype molds are, in fact, increasingly being produced in a nearly fully automatic mode on high speed numerically controlled milling machines. Due to limitations in the process, the core and cavity inserts are typically machined from aluminum with very small end-mills used to provide reasonably detailed features. While this mold-making approach does provide very precise cost estimates and low costs, the resulting molds are comparatively soft and often not appropriate for molding high quantities. Higher strength and wear resistant aluminum alloys, however, have recently been and continue to be developed that are increasingly cannibalizing conventionally manufactured steel molds.