A Computer-Based Economic Analysis for Manufacturing Process Selection

Manocher Djassemi
California Polytechnic State University
djassemi@calpolystate.edu

Abstract

An important part of financial planning in product development is considering whether the capital expenditures meet volume and cost goals. A good business plan should provide investors with the implications of process selection on the company's bottom line. It is estimated that there are least 1000 manufacturing processes and sub-processes. Considering the number of process choices and quantity of cost data, an economic analysis for process selection may pose a challenge for decision makers. This paper provides an insight to Ashby's cost modeling method for generating an estimate of unit product cost. The cost model provides a broad indicator for competing processes for shaping a product at the early stage of product development. This model takes into account the cost of resources associated with manufacturing a component. Using the Cambridge Engineering Selector software the impact of various cost factors on process selection is investigated.

Introduction

With advancement of technology in recent decades and increasing level of sophistication and variety in manufacturing processes, facility planners and engineers may face a nontrivial task of process selection. The implication of manufacturing process selection on a company's management is it may indirectly influence widely varying aspects such as company policy, availability of facilities and trained personnel [1]. The selection of a process for shaping a component is not an isolated task. It requires considering several factors among which the type of material, shape and cost of component are the most significant ones. Figure 1 depicts the interaction among major factors involved in material and process selection.

It is estimated that there are between 40,000 and 80,000 materials available today and at least 1000 different ways to process them [2]. Considering such variety of materials and processes, the economic analysis for selecting a process may require handling a large amount of data and performing calculations. The use of conventional data sources, e.g., handbooks, datasheets, is not sufficient to manage the growing volume of data for materials and manufacturing process selection purpose. While numerous experimental academic papers have been published in recent years [3][4], only a few commericial online and CD-ROM based material and process selectors have emerged. One of the most widely publicized CD-ROM systems known as Cambridge Engineering Selector (CES), developed by Ashby [5]
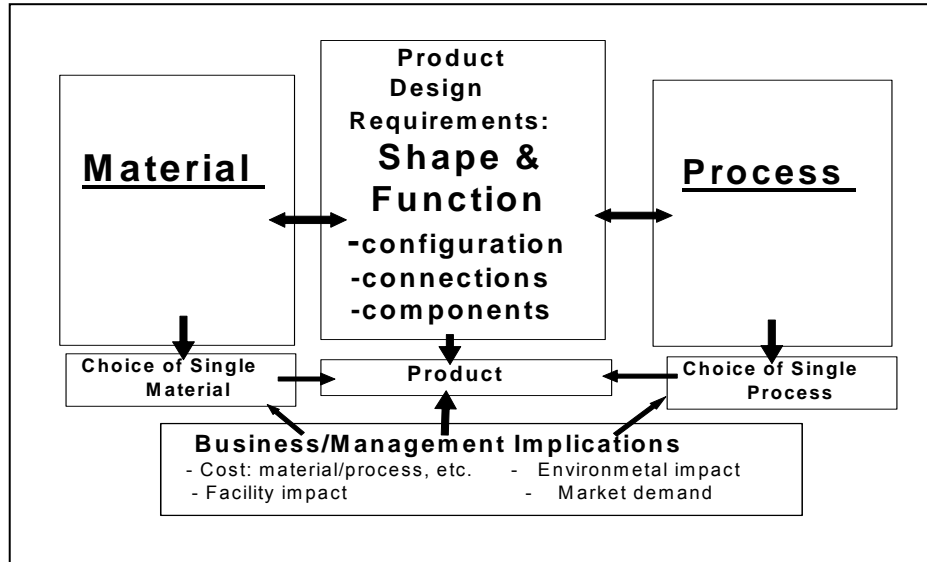
Figure 1. Integrated process, material and product design

and commercialized by Granta Design Limited. Originally conceived as an educational tool, CES's evolution into a user-friendly software system, combined with the quantity of technical data it offers, allows its application to any industrial situation [6]. It also provides graphical selection and ranking methods as well as an in-depth analysis tool for research and education. CES offers several capabilities including a) material property data for metals, polymers, ceramic and composites, b) material selection using multiple attributes, and c) a process selector module. The process selection module of CES is perhaps the only available commercial software for such purpose. The module offers a cost modeling function for economic analysis of various material shaping processes which is the focus of this paper.

Manufacturing Process Selection

In general, a manufacturing process selection identifies feasible processes by screening and eliminating those which do not satisfy certain constraints. Often such process selection is prerequisite to equipment selection which traditionally has been accomplished using the general knowledge and expertise of engineering staff. However, with growing number of processes and sub-processes, an elaborated and systematic selection method is needed to take into account the various factors such as material, product design and environmental constraints, while meeting capital and operating cost limits. Figure 2 shows a sequence of typical steps involved in a manufacturing process selection. The sequence incorporates the following attributes for search and screening of processes:

Material Class: Includes the type of material to be used from metal, polymers, ceramics or composites categories.
Physical constraint: Includes the mass of a product.

Shape Constraints: Include a component's section thickness and its overall geometry, e.g. circular, non-circular, hollow, or solid.

Process Characteristics: A decision must be made whether the process should be a primary process such as casting or forging or a secondary process such as machining. It is also necessary to determine whether the process should be a discrete or continuous one.

Environmental Constraints: Environmental concerns regarding a manufacturing process may include gases, fumes, heat and noises generated by the process. The amount of energy required for processing a material may also be considered in the selection process.

Economic Constraints: Include capital equipment cost, tooling cost, economic batch size and so forth. The economic constraints will be discussed in more detail in the next section.
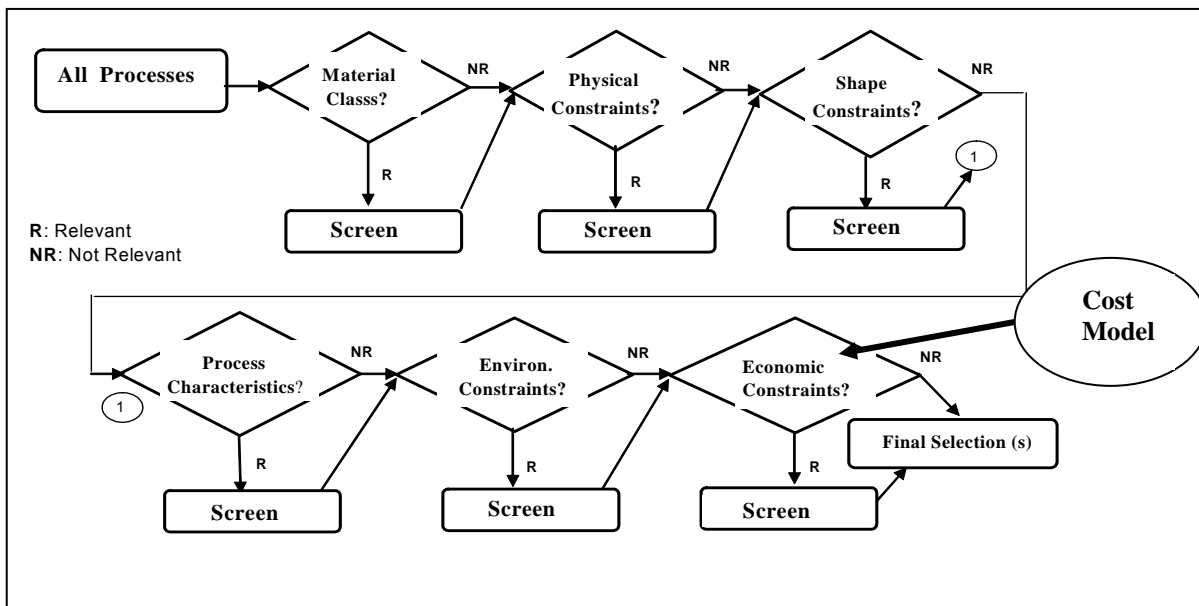

Figure 2. Selection steps for a manufacturing process

Economic Consideration

To rank the relative cost of investing on a manufacturing process, we used a resource-based cost modeling approach developed by Esawi and Ashby [6]. This model takes into account the cost of resources associated with manufacturing a component. The cost model does not provide an accurate cost estimate for bidding purpose or calculating profit and loss. It is basically a broad indicator for competing processes for shaping a product at the early stage of product development or business planning. The model is comprised of the cost of common factors in the manufacturing of a product, including materials, capital equipment, and overhead (labor, energy, research and development, etc). Other parameters included in the model are expected production volume, product mass, production rate, etc.

Based on this cost model a relative cost index (RCI) is defined by Esawi and Ashby [6] as shown in equation 1. In this equation, RCI represents the overall cost per unit of product. The definitions of parameters used in the expression are shown in Table 1. The table indicates which data can be extracted from the process selector database and which one must be provided by the user. This cost model has been embedded in CES software which allows the user to generate various charts for economic comparison of alternative manufacturing processes. An experimental process selection with emphasis on cost modeling function is presented in the next section.

$$RCI = \left(\frac{M_c \times C_m}{M_u} + \frac{T_c}{Q} \right) \left(1 + \left(\frac{Q \times C_l}{T_l} \right) \right) + \left(\frac{C_l}{P_r \times 60} \right) \left(O_v + \left(\frac{E_c}{T_{cw} \times 24 \times 365 \times E_u} \right) \right) \quad \textbf{Eq. (1)}$$

Table 1. Parameters used for economic consideration.

Parameter	Full Name	Data Provided By User	Data Provided By CES
C_m	Component Mass	√	
C_l	Component Length	√	
Q	Production Vol.	√	
O_v	Overhead Rate	√	
T_{cw}	Capital Write-off Time	√	
Eu	Load Factor (machine utilization)	√	
M_c	Material Cost		√
M_u	Material Utilization Fraction		√
T_c	Tooling Cost		√
E_c	Equipment Cost		√
T_l	Tool Life		√
P	Production Rate		√

The Experiment

In this experiment, we applied the process selection sequence as depicted in Fig. 2 to a mechanical fastener. Mechanical fasteners are common assembly hardware which can be made of a wide range of materials. From a user's standpoint, the desirable attributes of a fastener may include lightweight, high shear and wear resistance, good corrosion resistance, and be inexpensive. From a manufacturing standpoint, it is desirable to produce the component with minimal equipment, tooling and energy costs while meeting the product specifications. A preliminary material selection analysis indicated that the zinc aluminium

alloy is the best material for this application. Figure 3 displays the process-related attributes for the fastener. Knowing the material type and process attributes, we proceed to process selection stage.

Material Class	Zinc Aluminum
Mass	0.2-0.4 oz
Section Thickness	0.1"-0.3"
Shape Class	Prismatic-Solid
Primary	Yes
Discrete	Yes
Tolerance	<± 0.01"
Roughness	<60 μinch
Expected Demand	1000,000

Figure 3. Process attributes for mechanical fastener

Stage 1: Physical constraints

Figure 4 shows a plot of material class vs. product mass. A selection box for the mass range of 0.2-0.4 ounces is shown at the bottom of the plot. This box identifies 19 shaping processes which satisfy the product design requirements for material class (Zinc Aluminium) and
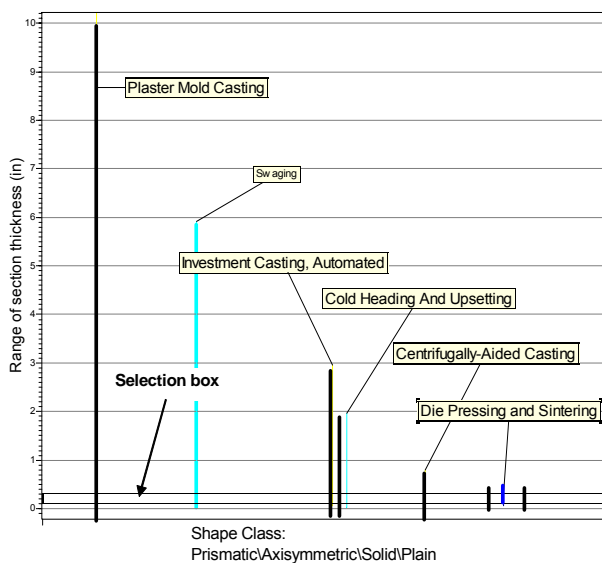
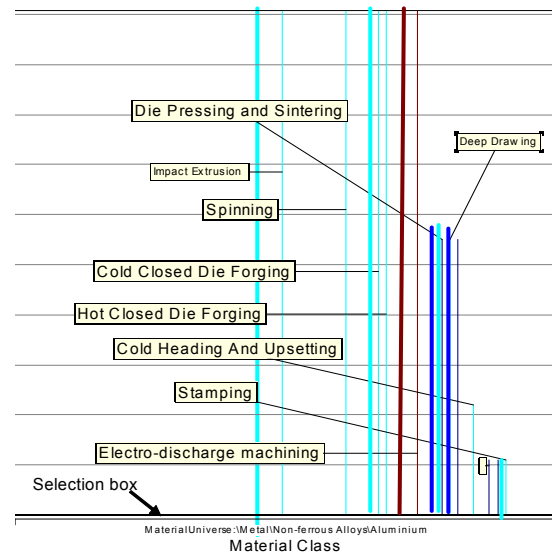Figure 4. Product mass vs. material class

Figure 5. Process selection based on part thickness and shape class.

product mass. The screened processes include some casting processes (diecasting, investment casting, etc.), cold forming processes (swaging, cold heading, etc.), and machining processes (milling, turning, machining, etc.).

Stage 2: Shape constraints

Figure 5 exhibits a bar chart that displays two design related constraints: shape class (cylindrical) and thickness of fastener. The selection box is placed on the chart for a thickness range of 0.1"-0.3." Eight processes from stage 1 failed at this stage. Some of the remaining processes are labelled on the chart.

Stage 3: Process characteristics

Generally, manufacturing processes can be characterized as primary processes such as casting/forging processes or secondary processes such as milling or EDM. To minimize material waste we chose "primary" as a selection criteria. Manufacturing processes can be also characterized as discrete or continuous production. In this case we chose "discrete" option to screen the processes.

After applying these two constraints, eight processes passed this screening stage. Processes such as grinding and polishing, which are considered as secondary process, did not pass this stage. The eight processes which successfully passed all three stages were:

CLA/CLV Casting
Cold Heading and Upsetting
Plaster Mold Casting
Centrifugally-Aided Casting

High Pressure Die Casting
Investment Casting, Automated
Die Pressing and Sintering
Swaging

Stage 4: Environmental constraints

Two common factors which directly affect environment are emission and toxic waste generated by a process. However, the level of emission and toxic waste to a large degree depends on what material is processed. While numerical environmental data for process comparison are not readily available, it is possible to use some descriptive process records for screening purpose. For instance, CES provides the following environmental and safety statement about casting processes:
"Fine dust and harmful binder fumes. Explosion/fire risk due to alcohol carrier. Protective face masks and well ventilated working areas are recommended."

In our experiment, we did not consider environmental factors due to lack of numerical data in CES. However, any significant environmental concern such as the one described above must be available before final decision is made.
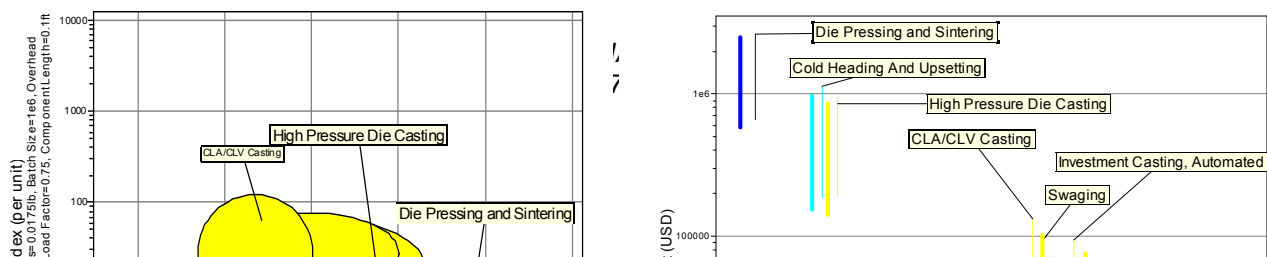
Figure 6. Screening of processes based
on overall cost.

Figure 7. Equipment costs for final
eight processes.

Stage 5: Economic Constraints (Cost Modeling)

At this stage we ranked the final eight shaping processes based on economic requirements.
Figure 6 displays a bubble chart of production rate vs. unit product cost (RCI) for the final
eight processes. The parameters used in calculating RCI are shown in the same figure. Each
bubble represents a range of production speed (horizontal axis) and product cost (vertical
axis). As can be seen, the bubble for cold heading/upsetting process is in the lower right
corner of the chart, indicating this process has the lowest overall cost ($.01-$0.11 per unit)
and has fastest production rate (1000-10,000 units/hr) while the CLA/CLV casting process at
the upper left corner of the chart is the most expensive ($10-100 per unit) and has the slowest
production rate (7-9 units/hr).

Figure 7 shows a bar chart of equipment cost for the eight processes under consideration.
Although the cold heading/upsetting process has the best overall cost and production rate, it
is the second most expensive process ($188,000-$1,300,000) in terms of machinery cost,
while the plaster molding process costs less than $10,000. This data can be useful at early
stage of product development and business planning since it provides an estimate of required
initial capital outlay. The conclusion that we can make here is that the cold heading/upsetting
process requires a capital investment between $188,000 to $1,300,000, and over five years
of capital write-off and producing 1,000,000 parts, overall, it is the most economical
selection.

Finally, we plotted the cost of unit product versus economic batch size (Fig. 8) for cold
heading process using cost modeling function of CES. This plot provides a visual tool for

determining the size of job order that justifies the investment on this particular process for production of the fastener.
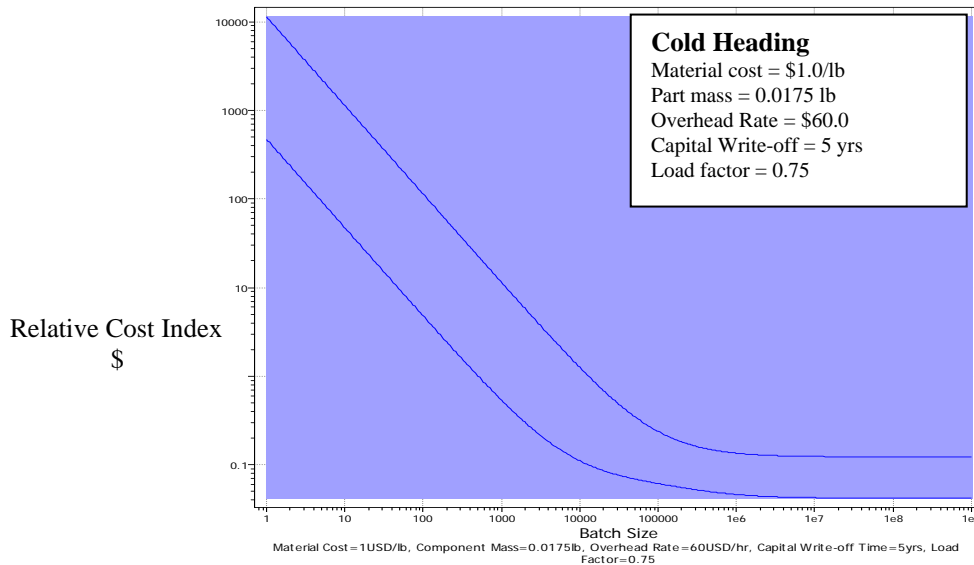

Figure 8. Unit product cost vs. batch size

Conclusion and Further Work

This paper provided an insight into a computerized cost modeling method for selecting a manufacturing process. This approach can be useful at early stage of product development and business planning by applying a series of search and screening stages for narrowing down a large list of processing options in a short amount of time.

Although a computerized process selector can be an effective tool for finding the appropriate process, facility planners must be aware that this kind of software can not be used as an equipment selector. As it was shown in the experiment, the capital cost of final selection, cold heading/upsetting process, ranges from $188,000 to $1,300,000. This wide price range indicates the availability of a broad range of equipment in the market. Additional technical and cost analysis are needed before a final decision is made to acquire a specific piece of equipment to make sure it is compatible with the attributes of selected manufacturing process and also satisfies any constraint that may exist in a particular facility.

Another observation from this study is the cost modeling function of the only commercialized manufacturing process selector (CES) is limited to shaping process e.g., casting, forging, extrusion. No cost modeling function is available for material joining, material removal and surface finishing processes. This may be due to difficulty in obtaining data for various cost parameters. In case of material removal processes, the amount of scrap is a variable parameter which may have a significant impact on product cost. Thus, it is

appropriate to develop a new cost model that incorporates such parameter for economic comparison of material removal processes with other non-chip producing processes.

References

[1] Lovatt, A.M., Shercliff, H.R., "Manufacturing process selection in engineering design. Part 1: the role of process selection," Materials and Design, 19(5-6), 1998, p 205-215.
[2] Ashby, M.F. Brechet, Y.J.M., Cebon, D., Salvo, L, "Selection strategies for materials and process," Materials & Design, 25(1), 2004, p 51-67.
[3] Chakraborty, S., Dey, S.," QFD-based expert system for non-traditional machining processes selection," Expert Systems with Applications, 32, 2007, p1208-1217.
[4] Ferrante, M., Santos, S.F., Castro, J.F.R, "Material selection as an interdisciplinary technical activity: basic methodology and case studies," Material Research, 3(2), 2000, p1-9.
[5] Ashby, M.F, "Material selection in mechanical design," 2nd ed., Oxford, UK: Butterworth Heinemann, 1999.
[6] Esawi, A.M.K., Ashby, M.F, "Cost estimates to guide pre-selection of processes," materials & design, 24(8), 2003, p605-616.

Biography

MANOCHER DJASSEMI is currently an associate professor of industrial technology at the California Polytechnic State University. His areas of interest include manufacturing processes, material and computer-integrated manufacturing. He is a certified manufacturing engineer by the Society of Manufacturing Engineers.