

Combining the Resource Consumption Model (RCM) and the Cambridge Engineering Selector (CES) to Analyze Product Design

Dr. Richard Jerz

*Ambrose Institute of Industrial Engineering
St. Ambrose University*

Keywords: Process planning, process costing, process design, cost estimating, capacity planning.

ABSTRACT

It has been reported that as much as 70 to 80 percent of the cost to produce a product is determined during the conceptual product design stage; therefore, product decisions made at this point are critical [1]. Inherent part design features, such as material, shape and features, quality, and functional specifications influence product cost. Additionally, manufacturing strategies and manufacturing process parameters such as production resource requirements, production volume, capacity, and cycle time affect product cost. Product design and manufacturing process selection are often separate functions within many industrial organizations. Engineers need systematic ways to concurrently address both product design and manufacturing process selection.

The Cambridge Engineering Selector (CES) is a tool that focuses on material, process, and shape combinations of product design. The Resource Consumption Model (RCM) is a tool that focuses on production process resources, resource costs, production volume, production capacity, and manufacturing cycle time. Both tools help identify viable manufacturing process alternatives to meet stated manufacturing objectives.

A product design scenario is identified and analyzed using both CES and RCM. RCM methodology complements CES, providing a powerful approach toward computer-aided process planning. The combination of these tools lead to better product design decisions.

PRODUCT DESIGN AND MANUFACTURING PROCESS SELECTION

The manufacturing process involves a transformation of raw materials into finished goods. Customers express their needs, product designers transform customer needs into product and part specifications, manufacturing selects the processes and produces the products, and the customers purchase the products. The goal in the transformation process is to derive the best methods to produce the best product while maintaining customer and marketing functional requirements.

It is sometimes assumed that product design and process design are sequential decisions. In fact, these decisions need to be considered simultaneously. The way a product is designed affects how it is to be manufactured and its cost, which affects product pricing and how many people buy it, which affects production capacity, which affects process costs, which again affects product pricing and how many people can afford to buy it. Better decisions can be made if product design, process design, and cost analysis can be considered concurrently. If these decisions are not viewed as a whole, a decision in product design that might offer the best technical solution could cause the product to fail because it makes the product less attractive to customers or increases the cost of the product beyond the affordable reach of most consumers.

Computer-aided process planning tools (CAPP), computer-aided design tools (CAD), and computer-aided engineering tools (CAE) are improving to offer a computer-integrated manufacturing (CIM) environment. Much more work, however, remains. Developing integrated tools is a complex problem. Many design and analysis functions must be done which often requires specialized engineering knowledge and training. Today's solution is to hire a variety of engineers,

each possessing specialized knowledge. However, as computer hardware and software become more capable, comprehensive, and easier to use, fewer but smarter engineers will be hired. Someday an engineer's job will include product modeling, functional analysis, and manufacturing process selection. This will only be accomplished using advanced computer-based tools.

Two computer-based tools are explored within this paper. CES is a commercially available tool that helps design products to satisfy a variety of design constraints (e.g., size, shape, strength, weight, stiffness), and identifies viable production processes. RCM is a research model that provides exploration into production process alternatives relative to cost, cycle time, and production capacity. Both products recognize that the vast domain of viable product and process design alternatives can be reduced to a smaller subset when a systematic investigation methodology is applied. The combination of CES and RCM provide a powerful solution for product and process design. In the future CES, RCM, and tools that are more advanced will be integrated with CAD and CAPP tools to provide a complete engineering toolkit.

THE CAMBRIDGE ENGINEERING SELECTOR

The Cambridge Engineering Selector (CES) is a methodology for choosing an optimal material, shape, and manufacturing process for a product design [2]. The selection of optimal material, shape, and manufacturing process is a balance between many factors (e.g., strength, weight, fracture toughness, thermal expansion, size, melting temperature, tolerances, and surface roughness). Although we might want to design a product that is the lightest, strongest, and cheapest solution, we realize that there is frequently no one best solution. Instead, a compromise between factors must be made that still satisfies most design objectives. Without CES, the selection of best material and process can be a random process (just select any one), a bewildering process (cannot select any), or a "do what has been done before" (variant) process. None of these guarantees an optimal solution.

CES methodology is a multi-step process. Each step lets an engineer focus on two factors at a time. As this is done, groups of materials get identified. In each successive step, additional design constraints get investigated to reduce the viable materials subset. Eventually, the intersection of all design constraints produces an acceptable material. If not, either the design itself or design constraints needs reevaluation, or a composite material, a newly engineered material, or a composite design is needed. The same procedure is followed for manufacturing process selection. When a limited set of materials and processes is identified, the selection among these becomes much easier.

Initially, CES methodology was performed using charts. Fig. 1 is one example for process selection, and shows regions of viable manufacturing processes considering a product's surface area and thickness requirements. The intersection of these two specific design requirements (e.g., 1m² surface area and 1mm thickness) identifies acceptable manufacturing processes (i.e., fabrication, machining, and cold working.) CES methodology is now available as a computer program that includes powerful graphical and optimization ability. The computer-based CES system is built upon relational database technology to manage the vast amount of product design information. Users can keep the CES database current and specific by adding new information to the database.

THE RESOURCE CONSUMPTION MODEL

Management has learned that the lowest cost process design is not always best, and that sometimes production time (i.e., response time) or reserve capacity (i.e., flexibly) may become more important. The resource consumption model for process design (RCM) was developed to address this situation [3]. It was believed that the relationships between cost, time, and capacity analysis could be developed mathematically, and when the formulae are applied across a production volume range and portrayed in simple to understand formats, management will make better process design decisions.

RCM better models the analysis and selection of process design alternatives for product manufacture. Several varieties of production economic models exist to aid production process design (e.g., return on investment analysis, break-even analysis, cost estimating, and design for manufacture), however, these fail to integrate sufficiently cost, production cycle time, production capacity, and economy of scale factors. These factors can become very important, especially when

evaluating the benefits of new manufacturing technologies and strategies. RCM provides greater understanding, fidelity and sensitivity analysis for process design than other methods.

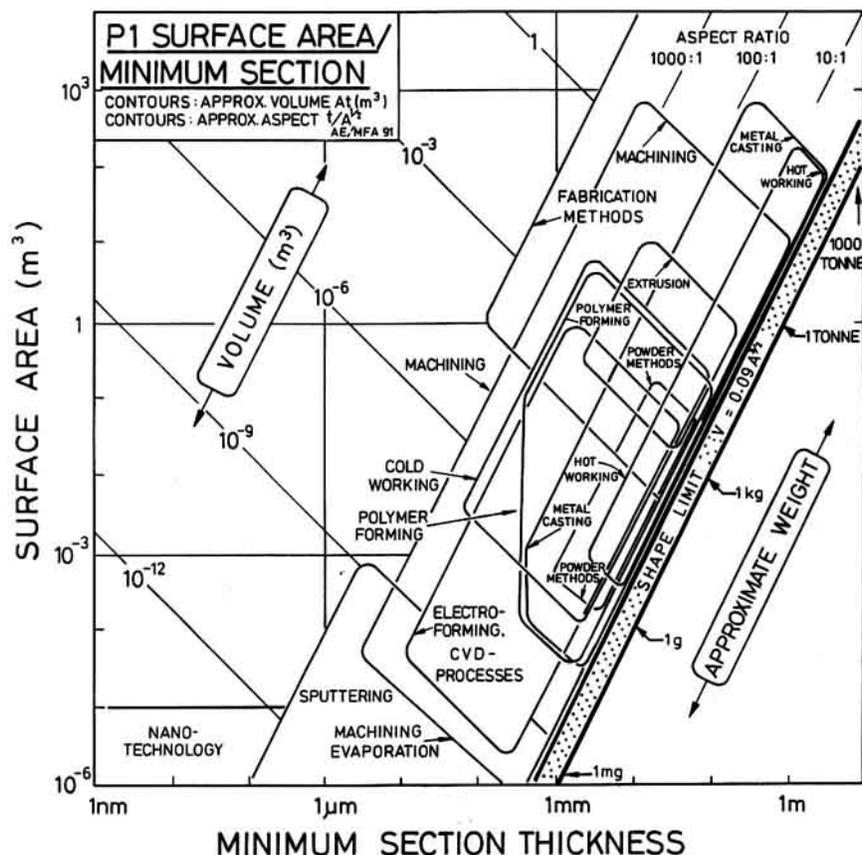


Fig. 1. Ashby's process selection chart. Source: M. F. Ashby

RCM's foundational concept is that part production consumes resources. RCM accounts for all resources, which can include equipment, labor, energy, material, tooling, and other consumables used by process designs. It characterizes resources generically and avoids the need for terms such as "fixed costs," "variable costs," "overhead," and so forth. For each resource, RCM performs quantity-based, time-based, and system-based calculations for a production volume range and determines the controlling condition. Resource results are accumulated to compare alternatives. Results are shown in both tabular and graphical formats. RCM easily provides both unit process cost and total process cost.

Fig. 2 depicts the many elements that compose RCM. When a product is designed, process design decisions must be made with respect to how it will be manufactured. Manufacturing alternatives are identified that satisfy the product's functional requirements (CES can be used at this step.) For each alternative, resources consumed are identified. Within RCM, fifteen parameters define each resource. Some parameters are cost-based, some are time-based, and some are system-based. RCM performs calculations that provide cost, time, and utilization information. Based on this information a process can be selected. If the results prove unacceptable, refinements to the process alternatives or new alternatives must be investigated. Like CES, RCM is an iterative process. The user may reinvestigate alternatives or resources as necessary by changing parameter values.

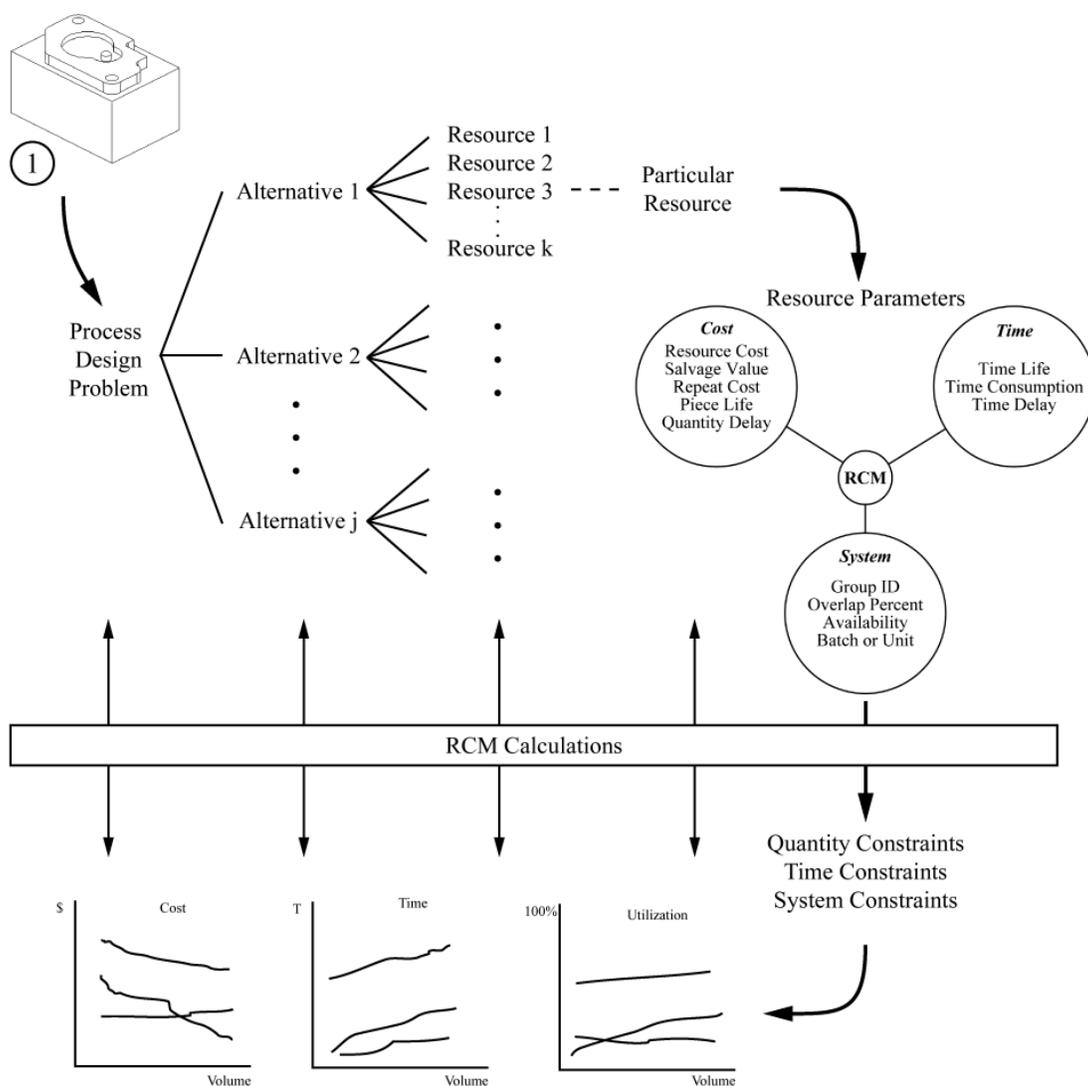


Fig. 2. RCM model overview.

Alternatives and resource information are managed using a database system. Depending upon the detail required, RCM can display cost, time, and utilization results for any individual resource, multiple resources, any individual alternative, or for up to six alternatives. The nature of the graphs and tabulated results change depending upon the user's selection. For example, Fig. 3 illustrates an average part cost comparison for three alternatives. Fig. 4 shows the average cost detail for six resources that compose one alternative's cost.

These figures show cost information, but RCM also produces time and utilization graphs. A computer model was developed for RCM so that many scenarios can be quickly understood.

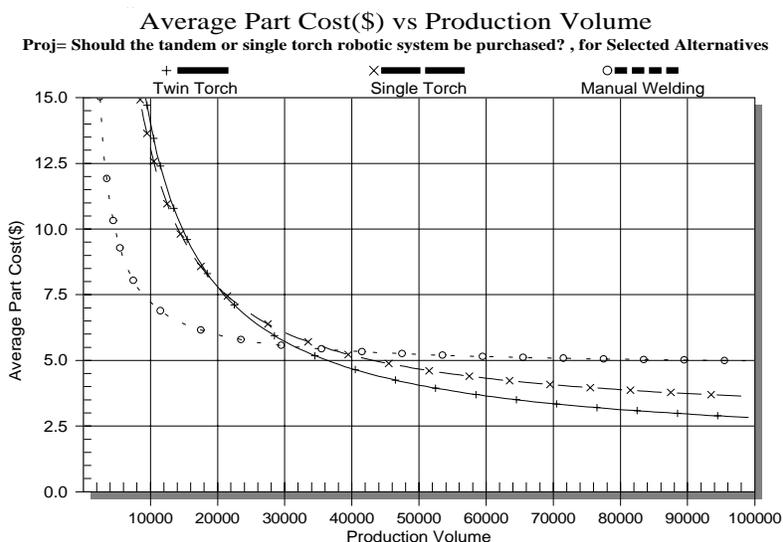


Fig. 3. Graph showing average cost for all alternatives.

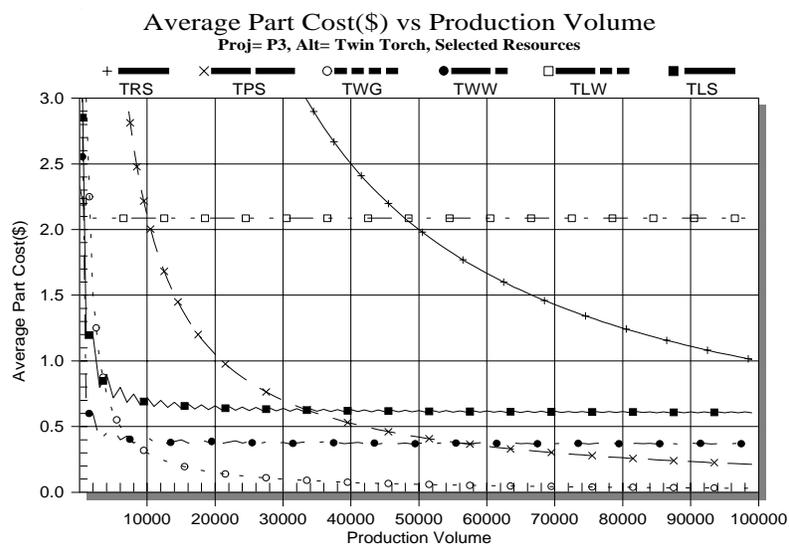


Fig. 4. Graph showing average cost breakdown for one alternative.

AN APPLICATION OF CES AND RCM: SHAKER TABLE DESIGN

An example, taken from M.F. Ashby [2], will show how CES and RCM can be used to design a product and manufacturing process. Consider a need to produce a shaker table (Fig. 5.) The table is to be made of a magnesium alloy, melting point = 905K; hardness = 800 Mpa; density = 1.78 Mg/m³ (it is assumed that this material was selected using CES's material selection methodology.) The diameter of the table is 2 m; the thickness of the table at its webs is 100 mm. The top surface and hub of the table are to be finished to a tolerance of ± 0.07 mm and a RMS roughness of 5 μ m. The finish of the remaining surfaces is not critical. The problem is to select the production process to manufacture the product.

The entire scope of this problem cannot be investigated within this paper. Instead, a more limited analysis will be performed to illustrate the major concepts.

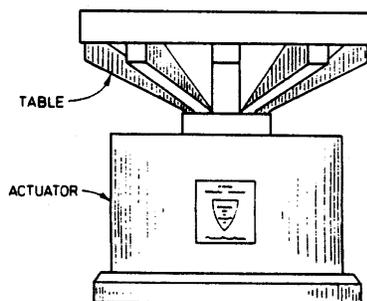


Fig. 5. A shaker table.

METHODOLOGY

Applying CES

Process selection charts from Ashby [2] are used to perform the stepwise investigation. The first step considers surface area and minimum section thickness (see Fig. 6.) In this figure, the gray

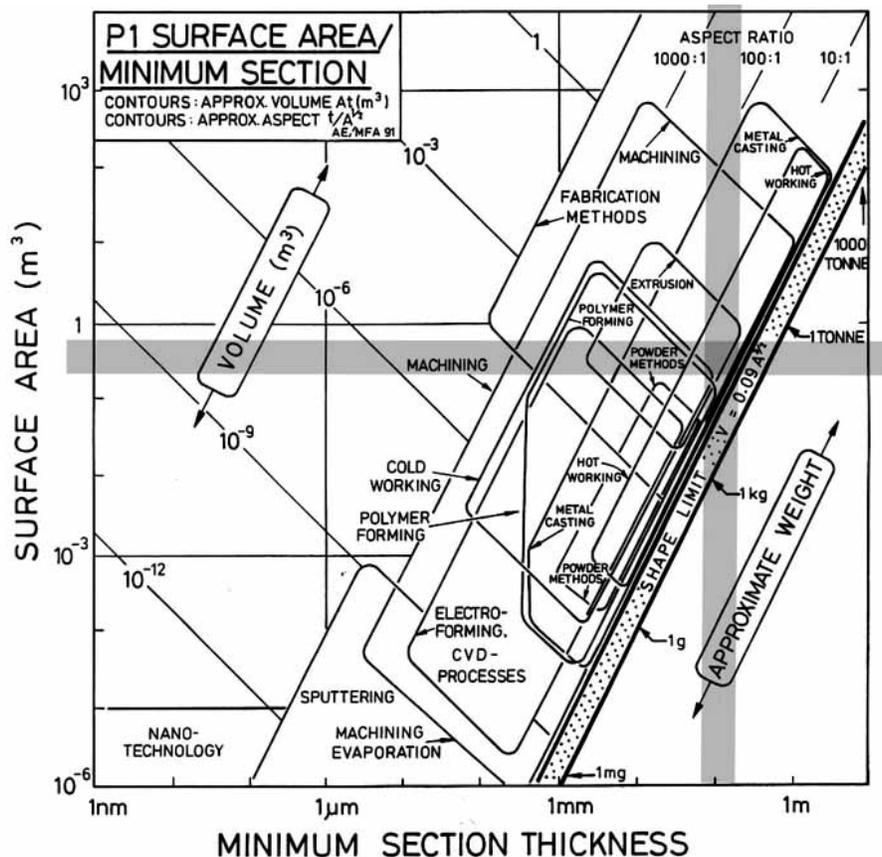


Fig. 6. Process selection chart for process alternatives.

bands have portrayed the required surface are and minimum section thickness. It is typical to use a band instead of a line to allow some design criteria flexibility. On this chart, the viable manufacturing processes are: hot working, extrusion, metal casting, machining, fabrication methods, polymer forming, and cold working.

Continuing the investigation and using chart P3 - size versus melting temperature for casting processes, the viable casting processes are: sand casting, full mould casting, and plaster mould casting. Chart P4 – melting temperature versus hardness, identifies hot working, casting, and cold working. Lastly, chart P5 – surface roughness versus tolerance range, identifies polishing, grinding, and honing.

Since there is no intersection of all viable processes it is likely that two manufacturing operations will be required. The first operation might be casting, hot working, or machining. The choice between these requires more company-specific information; its manufacturing strategies, its available equipment, and a detailed cost analysis. The second process may be grinding, honing, or polishing. This decision also requires further analysis.

Applying RCM

RCM can be used to analyze, in detail, the production process alternatives. For this paper, RCM will be used to determine only the first production process – a decision between casting, machining, and hot working. In the real situation, RCM would be used to analyze both manufacturing stages.

Referring to Fig. 1, the first step for applying RCM is to identify viable production processes. CES was used in the previous section to identify the viable production processes: casting, hot working (or “forming”), and machining.

The next step is to identify resource requirements for each alternative. This paper will use a condensed set of resources to illustrate the major features of RCM. Consider that all alternatives require equipment, material, labor, and fixtures resources. For machining, a perishable tooling resource (i.e., cutting inserts) is required.

Table 1 provides cost information for each resource. “Cost” is only one of the fifteen resources parameters used to describe a resource. Fifteen parameters are needed for RCM to analyze cost, production time, and utilization. Cycle time is a second parameter, and for this example, it will be made constant for all resources. A three-dimensional table would be needed to describe all parameters for all resources. For simplicity, cycle time for each production process is shown at the bottom of Table 1. Additional resource parameter values (such as resource life) are entered into the computer model by the author.

Table 1. Manufacturing process alternatives and resources.

Resource	Production Process		
	Machining	Casting	Hot Working
Equipment Cost (\$)	200,000	2,000,000	400,000
Material (\$)	30	10	25
Labor cost (\$/hr)	20	100	23
Fixture cost (\$)	20,000	400,000	60,000
Perishable Tooling Cost (\$)	2	0	0
Cycle Time (min)	15	1.5	5

The RCM computer model allows easy investigation to the behavior of individual resources, individual alternatives, and all alternatives as data is entered. Graphical and tabular results are

generated for cost, time, and utilization that improve the understanding of each process alternative. The production range (x-axis) and y-axis range is changed to focus into specific results. Fig. 7 shows the graphic results for average product cost for each alternative under one set of conditions. Fig. 8 shows the total production time for each alternative. These are only two of the many graphs there were generated to get to this point. Graphing the results is not very long and using RCM is not as difficult as might be expected¹.

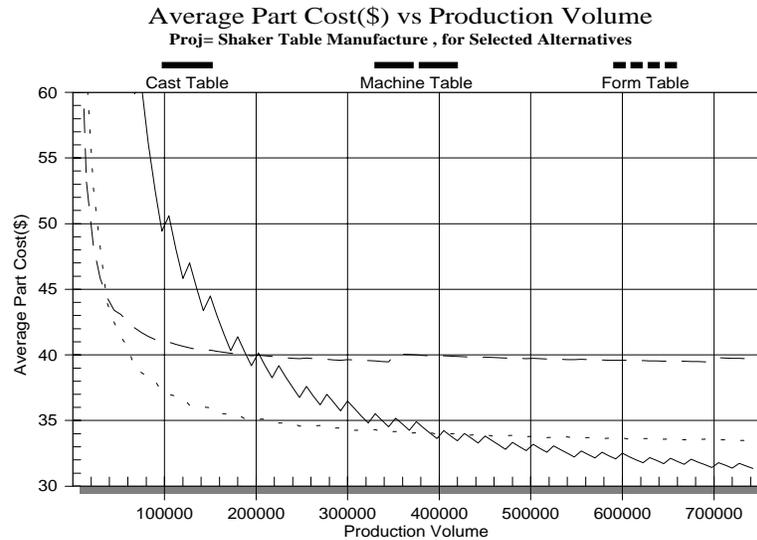


Fig. 7. Average cost for shaker table process alternatives.

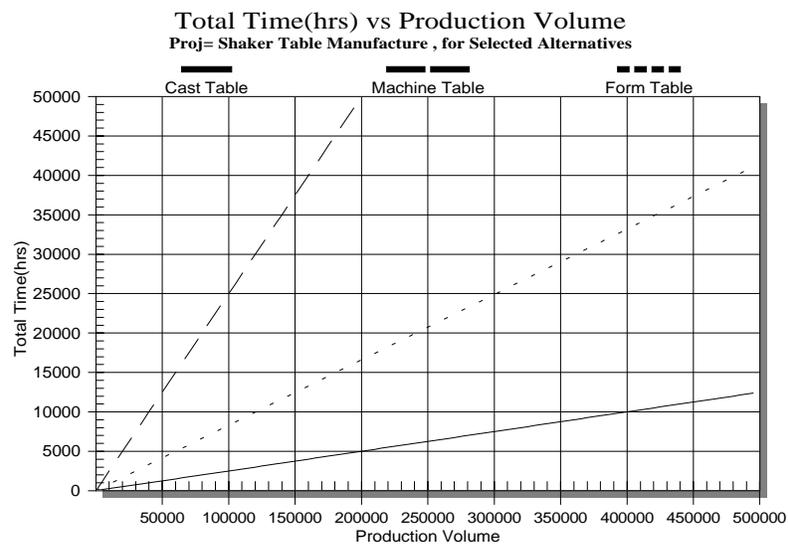


Fig. 8. Total production time for shaker table process alternatives.

¹ Most charts are produced in less than 3 seconds on a 300Mhz, 128MB RAM PC.

RESULTS

CES used shape and feature criteria to determine viable production processes. In this example, it suggested casting, machining, or hot working. RCM used the CES suggested production process for its analysis.

In our simple example, RCM shows that the best production process based on cost depends on production volume (see Fig. 7.) At production volumes less than approximately 37,000 units, machining is best. From 37,000 to approximate 400,000 units, forming is best. At greater than 400,000 units casting is best. RCM also lets one see the average part cost immediately on this chart. If this solution is unacceptable, the user can explore each alternative and its resources to investigate what would have to change to reach an acceptable solution. Fig. 8 shows that casting offers the fastest production time. If, for example, management wanted to implement a just-in-time strategy, time results might be more important than cost results. It was also learned (graph not shown) that the casting process has the lowest utilization, an important factor if management wants to produce other products with this equipment or anticipates a greater product demand.

CONCLUSION

The example briefly illustrated how CES and RCM each consider different characteristics of product and process design. Together, they become a powerful set of computer-aided process planning tools. When these methodologies are provided as computer programs, their power is dramatically increased. "What-if" analyses become relatively easy and timely to do. For example, a change in a products weight may cause changes in production process alternatives, which could change RCM results.

Both CES and RCM computer models use relational database technology. Both recognize that the vast amount of engineering knowledge is best managed in a database environment. Engineering equations are incorporated within the database application. Both tools acknowledge that graphical results can help engineers understand and decide more quickly which product design changes are most important and how the changes impact the production process selection.

Although the combination of CES and RCM provide a powerful solution to product and process design, neither provides a complete toolset for the engineer. For example, neither does detailed, process specific calculations such as feed and speed calculations for machining operations. Another process planning module would be required for this level of process planning. RCM might then interface with this module and use its cycle-time and other results for RCM analyses.

In the future, CES and RCM should become part of a larger computer-integrated environment. The need to embed these tools with CAD and CAE tools exists. The future is very promising when one looks at the capabilities of today's existing CAD products. CAD software already integrates many engineering tools that were once separate products.

CES, as a commercially available product, has a proven record of helping product and process design. RCM remains as research. RCM successfully demonstrates that new process design models can be developed utilizing mathematically intensive concepts and implemented using modern computational tools. The comprehensive process modeling that RCM achieves is very difficult, if not impossible to duplicate using cost accounting, engineering economics, cost estimating, break-even analysis, or other methodologies. Both tools help management make better long-term strategic business decisions more confidently.

REFERENCES

- 1) E.P. DEGARMO, W.G. SULLIVAN, J.A. BONTADELLI, and E.M. WICKS, *Engineering Economy*, 10th ed., Prentice Hall, Upper Saddle River, New Jersey (1997).
- 2) M.F. ASHBY, *Materials Selection in Mechanical Design*, Butterworth Heinemann Ltd., Oxford (1992).

3) R. JERZ, *A Resource Consumption Model (RCM) for Process Design*, Ph.D. Dissertation, The University of Iowa, Iowa City, Iowa (1997).