MICRO-COMPUTER BASED COST ESTIMATION FOR THE SMC PROCESS

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ABSTRACT

As part of an industry sponsored research program at the Massachusetts Institute of Technology, an interactive computer model for estimating the cost of fabricating SMC components has been developed. This model is technically founded; inputs to the models include processing variables, material properties, and component design parameters. The model can be used to estimate piece costs and to perform sensitivity analyses. Currently, it is being used, along with other fabrication cost models, by the automotive and aerospace industries and by materials suppliers.

The methodology, scope, assumptions, and limitations of the SMC cost model are presented. An estimate of the cost of fabricating a SMC hood is presented as a case study.

GENERALLY, DESIGNERS AND MATERIALS engineers do not have adequate knowledge of costs. Much of their knowledge is embodied in simple rules-of-thumb, like double the material cost to estimate the total. Yet their decisions - the design of the component or the material from which it is to be made - establish most of the final cost. In light of this observation, it seems inexplicable that they are not given better tools for performing cost estimations.

Typically, managers also have inadequate tools for estimating costs. However, their needs and wants are different from those of engineers. Managers usually have access to detailed cost information, but do not have a framework for quickly and conveniently synthesizing this information into a technically accurate cost estimate. Frequently, they too must resort to the use of rules-of-thumb.

The SMC cost estimation program, as described herein, quickly, accurately, and consistently estimates the cost of fabricating SMC components, and is being used by designers, engineers, and managers of both the OEM's and material suppliers.

METHODOLOGY

The SMC cost estimating program developed at the Materials Systems Laboratory (MSL) can be described as a "process model" that has been outfitted with the economic information necessary to yield cost estimates. As a process model, its usefullness is not limited to a given type of component, set of materials, or processing environment. Rather, it can be used to model the full range of SMC fabrication.

The starting point in building any process model is to understand the process. Years of hands-on experience lead to the best understanding; however, this approach is not very expedient. A good understanding of the SMC process was obtained by constructing a process flow diagram that traces the flow of materials and energy, and depicts the primary and auxiliary equipment of the process. Such a process flow diagram is the starting point in building any technical cost model.

The second and most time consuming step in the methodology is data collection. Data requirements for the SMC model include materials prices, SMC formulations, equipment prices, labor wages, etc. These data provide the means for transforming the conceptual

SMC process model into a model which estimates the cost of fabricating a component. Data requirements and sources are described more fully in the following sections.

Where possible, raw data were refined into relationships. For instance, a table of the prices of various SMC presses was reduced to an equation that relates price to clamping force. Similarly, a relationship for the cycle time was derived from case study data of molded SMC components. Relationships were used in place of tables wherever possible since they add flexibility to the model, albeit at a small loss of accuracy.

The final step in the methodology is validation and refinement. In this stage, estimated values of the cost of SMC components were compared with their "known" values, and the differences were noted and analyzed. As necessary, the model's data and relations were revised. However, in all of these validations, the source and assumptions of the "known" values were carefully checked, since "known" values were often computed on a different basis, and in some cases they were downright wrong.

As a finale to model building, documentation was written. The model's document should not only describe how the model works, but also should outline the key assumptions and cite sources of data. The SMC cost estimating model was documented by these guidelines.

The finished model provides accurate estimates of the costs associated with the process. In the following sections, details of the SMC cost model are provided.

COST MODEL STRUCTURE

The SMC cost estimating model covers the main processes associated with SMC molding. These two steps are: 1) making the SMC sheet, and, 2) molding the SMC sheet into a component. The SMC model is organized on a Lotus 1-2-3 spreadsheet in four major sections. These are:

1. Formulation Specification
2. Sheet Line Calculations
3. Sheet Molding Inputs
4. Molding Cost Estimate

The inputs, formulae, and assumptions relevant to each of these sections are summarized in the following pages.

FORMULATION SPECIFICATION - The formulations section is used to specify the SMC formulation and its composition. A database of constituent materials is built into the model that contains resins, reinforcements, fillers, and additives. It also contains the current market price of each constituent. Users may specify any combination of these materials for their SMC formulation, or they may select from one of four prespecified formulations. The four prespecified formulations within the model are:

1. General Purpose: a generic SMC for non-structural, non-class A applications.
2. Low Profile 1: a formulation for components requiring class A quality surface finish, but not involving ribs or thick sections.
3. Low Profile 2: a formulation for class A body panels containing ribs.
4. High Strength: a formulation for structural applications.

SHEET LINE CALCULATIONS - This section of the model estimates the cost of producing SMC sheet from the specified constituent materials. The assumed technology for producing the sheet is based on the Navistar facility in Columbus, Ohio. Thus, cost estimates made in this portion of the model correspond to one scale and configuration of SMC manufacturing.

The cost SMC sheet is broken down into four major categories: materials, labor, capital, and energy. Each of these is estimated separately.

Materials costs are estimated from the market price of the constituent materials and from their percentages in the formulation. The cost of scrap for both the paste and finished sheet is also included in material costs.

Labor Cost is computed according to equation 1. The wages and number of laborers are specified exogenously ($13.00/hr and 4, respectively in the base case). The production rate is computed based on linear output, sheet width and thickness, and scheduled downtime for cleanup, and is estimated to be 4556 lbs per hour.

Capital related costs are computed using simple interest capital recovery. The total capital investment is estimated from the sum of the cost of the individual pieces of equipment to be $1.14 million. A fixed number of years (5 yrs) and a fixed interest rate (12%) are assumed. The annual capital recovery payment is distributed over the annual SMC production, yielding a

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$$\text{Labor Cost} = \text{Wage} * \text{Number of Laborers} / \text{Production Rate} \qquad (1)$$

capital cost per pound of SMC produced.

The cost breakdown for the low profile formulation is given in Table 1.

Table 1. - Cost Breakdown for Producing Low Profile SMC Sheet

	$/lb	percent
Materials	$.481	90.24%
Energy	$.001	0.13%
Labor	$.010	2.84%
Capital	$.036	6.80%
TOTAL	$.528	100%

The primary output of the sheet line section is the cost ($/lb) of the sheet. This value can be overridden in the sheet molding inputs section of the model to simulate the cost structure of a business which purchases, rather than produces, its SMC sheet.

SHEET MOLDING INPUTS - The sheet molding inputs are presented in Table 2. Many of these inputs (e.g., wages @ $13/hr, electricity @ $0.080/kWh) have default values built into the model and do not have to be input or changed each time the program is used.

The "process related factors" in Table 2 are used to estimate capital investment costs, overhead costs, and certain of the technical process variables (e.g., cycle time). Additionally, these factors underlie the capital accounting system of the model. Values and the functional relationships between the process related factors are based on industry averages obtained from a number of plants. The contents and use of this data set are described more fully in the following section.

Four of the inputs in Table 2, cycle time, tool cost, sheet cost, and press tonnage, are "optional". For each of these parameters, there are algorithms built into the program that will estimate their respective values based on the specified formulation, weight, maximum wall thickness, projected area, etc. Specifying any of these optional parameters directly overrides the internally generated values.

MOLDING COST ESTIMATE - The cost estimate which results from the inputs of Table 2 is presented in Table 3. The results are presented on the basis of $/piece, $/year, and percent of total cost. Additionally, for those cost elements associated with a capital investment, the model provides an estimate of the present value of the investment.

In addition to the cost elements, the model provides values for some of the key parameters on which the estimate is based. Cycle time, number of parallel streams, productive mold life, and press tonnage, are examples of this additional information.

As shown, the cost elements are broken into two categories; fixed and variable costs. The equations for estimating three of these elements are presented below. Specifically, the following equations are provided:

1. Material Cost
2. Labor Cost
3. Main Machine Cost

<u>Material Cost</u> - The cost of the materials used in the molding is estimated by equation 2. In this equation, the price of the SMC sheet is taken as the sum of all unit costs incurred in the sheet line, unless an "optional" override price is specified for the sheet.

<u>Labor Cost</u> - The cost of direct labor is estimated by equation 3.

<u>Main Machine Cost</u> - Main machine cost, which includes the cost of the press, hydraulic circuit, pump, and control panel, is computed based on press tonnage according equation 4. The machine cost coefficient ($8,621) and exponent (0.567) were determined from regression analysis, using data obtained from press manufacturers, principally Williams & White. These values reflect "typical" equipment, and would not apply for extreme levels of specialization. Press tonnage is computed from the product of two other input parameters,

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$$MC = Weight * Price / (1-Scrap) \qquad (2)$$

$$LC = C\text{-}time * Wage * Laborers / (Prd * Cav) \qquad (3)$$

C-time = Cycle Time as estimated in Additional Information
Wage = Direct Labor Wages including Direct Benefits
Laborers = Number of Direct Laborers per molding press
Prd = Productivity, i.e., (productive time / available time)
Cav = Number of Cavities in the mold

$$MMC = (\$8,621 * Press\ Tonnage)^{0.567} \qquad (4)$$

Table 2. - SMC Cost Model Molding Inputs
Generic SMC Hood

COMPONENT SPECIFICATIONS		
Formulation Number	2	
Weight	24.75	lbs.
Maximum Wall Thickness	0.145	in.
Projected Area	2888	sq in
Total External Surface Area	3255	sq in
OTHER INPUTS		
Annual Production Volume	40	(000/yr)
Number of Cavities	1	
Length of Production Run	3	yrs.
Scrap Rate (%)	6.0%	
Cycle Time <optional>	0	sec.
Tool Cost/Set <optional>	0	($000/set)
Sheet Cost <optional>	$0.00	/lb
Press Tonnage <optional>	0	tons
Dedicated Molding Equipment	0	(1=yes, 0=no)
EXOGENOUS COST FACTORS		
Direct Wages (w/ benefits)	$13.00	/hr.
Working Days/Yr.	240	
Working Hours/Day	16	
Capital Recovery Rate	12%	
Price, Building Space	$75.00	/sq ft
Building Recovery Life	20	yrs.
Price of Electricity	$0.080	/kwh
PROCESS RELATED FACTORS		
Machine Cost Coefficient	$8,621	
Machine Cost Scaling Exponent	0.567	
Accounting Life of Machine	6	yrs.
Direct Laborers Per Machine	2	
Mold Cost Coefficient	$19,308	
Mold Cost Scaling Exponent	0.76	
Baseline Physical Mold Life	800,000	cycles
Internal Molding Pressure	1500	psi
Auxiliary Equip. Cost (% mmch)	30.0%	
Installation Cost (% mmch)	10.0%	
Overhead Burden (% fc)	35.0%	
Maintenance Cost (% fc net ovhead)	3.0%	
Productive Time (% avail. time)	80.0%	
Cycle Time (intercept)	50	sec.
Cycle Time Scaling Factor	250	sec/in
Electrical Heat	0.50	kWh/lb
Electrical Mechanical Energy	0.08	kW/press ton
Floor Space (16 oz.)	251	sq ft
Floor Space Scaling Exponent	0.71	

Table 3. - SMC Cost Model Molding Outputs
Generic SMC Hood

VARIABLE COST ELEMENTS	$/piece	$/year	percent
Material Cost	$14.05	$561,802	58.0%
Utility Cost	$1.48	$59,125	6.1%
Direct Labor Cost	$1.17	$46,719	4.8%
TOTAL VARIABLE COST ===>	$16.69	$667,646	68.9%

FIXED COST ELEMENTS	$/piece	$/year	percent	investment
Main Machine Cost	$1.31	$52,505	5.4%	$673,236
Tooling Cost	$2.02	$80,773	8.3%	$242,320
Overhead Labor Cost	$1.43	$57,254	5.9%	
Building Cost	$0.19	$7,726	0.8%	$154,517
Installation Cost	$0.13	$5,251	0.5%	$67,324
Auxiliary Equipment Cost	$0.39	$15,752	1.6%	$201,971
Maintenance Cost	$0.04	$1,575	0.2%	
Cost of Capital	$2.01	$80,242	8.3%	
TOTAL FIXED COST ===>	$7.53	$301,078	31.1%	
TOTAL FABRICATION COST ===>	$24.22	$968,724	100.0%	

ADDITIONAL INFORMATION

Sheet Price	$0.53 /lb
Approximate Part Density	1.5 g/cc
Man-Hours Direct Labor	3594 /yr
Number Direct Laborers/Shift	2
Cycle Time	129.4 sec
Number of Parallel Streams	0.467936
Run-Time for One Machine	47%
Physical Mold Life	800000 cycles
Productive Mold Life	3.00 yrs
Required Building Space	2060 sq ft
Mold Complexity Ratio	1.1
Press Tonnage	2165.625
Sheet Line Utilization	12.1%

namely the projected area and the internal molding pressure (1500 psi).

Other Cost Elements - As can be seen from Table 3, there are other costs elements (e.g., tooling cost, cost of capital), as well as the "additional information" parameters (e.g., cycle time, run-time for one machine) for which the estimating equations have not been provided. This is done in the interest of brevity. The interested reader is encouraged to contact the author regarding the estimation of these parameters.

SENSITIVITY ANALYSIS

The utility of cost modeling may lie more in the area of performing sensitivity analyses than in performing direct cost estimates. Direct estimates obtained from cost models are rarely more "accurate" than plus or minus 20%, when compared with "known" values. Of course, twenty percent variation is not unusual for "known" values, when obtained from different cost accounting groups.

On the other hand, sensitivity analyses are generally quite accurate, at least for identifying trends and key cost drivers. Two such analyses are presented in Figures 1 and 2. The first shows the sensitivity of cost to cycle time, and the second shows cost versus production volume. In both cases, the total cost, variable costs and fixed costs are plotted.

Figure 1 illustrates that by reducing the cycle time from 3 minutes to 40 seconds, almost $5.00 per hood is saved. One third of this savings comes from the reduction of direct labor costs; two thirds comes from reducing the fixed costs, particularly the machine costs and the cost of capital.

The slope of the total cost curve in Figure 1 is the "fully loaded" shop cost including labor. In this case, its value is $140/hr. "Quick and dirty" cost estimates are often obtained by multiplying the loaded shop cost by the cycle time, then adding the cost of materials. However, the author warns against this approach, since loaded shop costs are hard to estimate, and they are extremely sensitive to variations in the size of the component and the annual production volume.

Figure 2 illustrates the sensitivity of cost to changes in annual production volume. Changing from 20,000/yr to 150,000/yr reduces the cost by $5.60 per hood by distributing the costs of the tooling, building, overhead labor, and capital over more pieces. The sensitivity is greatest at low volumes. The change from 20,000/yr to 40,000/yr reduces the cost of each hood by $3.73.

The jump in cost in Figure 2 that occurs at 90,000/yr is due to the addition of a second processing stream. Under the current set of assumptions, working 240 days per year, 16 hours per day, 80% productivity, with a cycle time of 130 seconds, it is only possible to produce 85,000 parts per press per year. The cost per hood to produce 90,000/yr is greater since another machine, set of tools, etc. must be purchased and paid for.

Of course, in most business situations, either the work year would be extended, or a third shift would be added, before another production line was brought on-stream. The SMC cost model can help management make these types of decisions by making it possible to examine the cost implications of alternative business scenarios.

ASSUMPTIONS AND LIMITATIONS

In order to build a cost estimating model, a number of simplifying assumptions must be made. When using a model, it is imperative that these assumptions be well understood. Three of the assumptions or limitations of the SMC model are discussed below.

1. The prices for the constituent materials were taken from manufacture's list prices. Actual transaction prices may be less than these values by as much as 20%.
2. The costs of finishing, particularly of in-mold coating, were not included in the model. The use of in-mold coating not only increases material and equipment costs, but also extends the cycle time, thereby increasing labor and overhead costs.
3. The model does not include the cost of rework or of rejected parts. While these costs are easy to estimate for specific SMC components produced at specific facilities, they are difficult to generalize to the SMC process as a whole. Rework and rejections are a function of fabricator skill and of the need for quality in application. Neither of these factors is easily incorporated into an analytical framework.

GENERAL OBSERVATIONS

Other cost estimating models have been developed at the Materials Systems Laboratory, including models of the

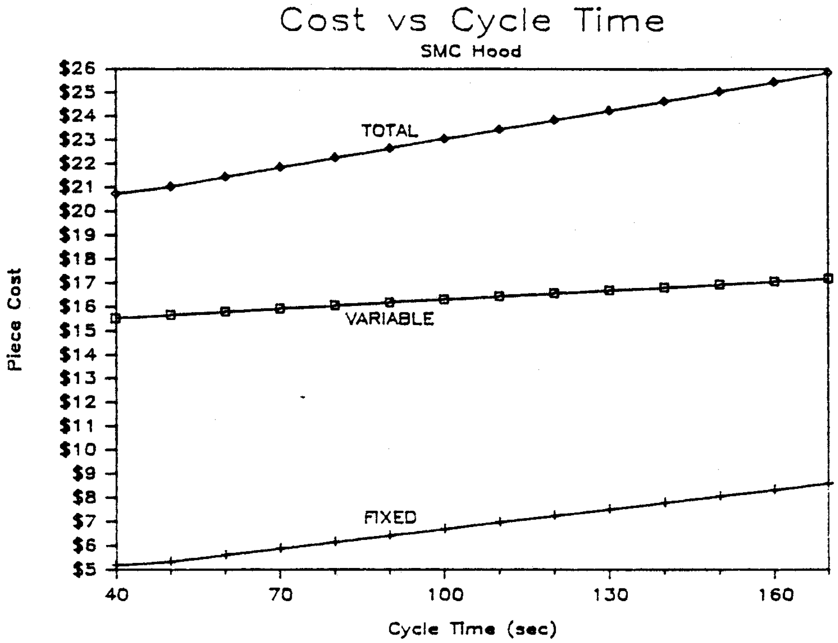

Figure 1. - Sensitivity Analysis
Cost as a Function of Cycle Time

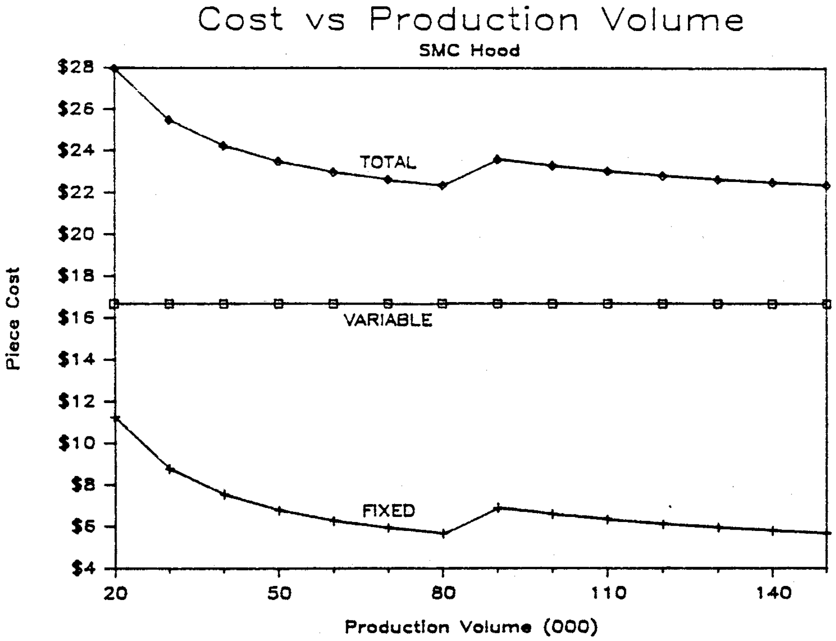

Figure 2. - Sensitivity Analysis
Cost as a Function of Annual Production Volume

injection molding, reaction injection molding, and steel stamping processes. These models have been used to study competition among materials in specific automotive body panel applications. While it is dangerous to generalize, the following impressions have been formed by the author regarding the relative economics of these processes. These generalizations are based on a consistent set of input assumptions to the various models, and the results are strongly dependent on these inputs.

Steel stamping is the low cost method for fabricating large numbers of body panels. Breakeven volumes with plastics fabrication processes range from 50,000/yr to 150,000/yr. Breakeven depends on both the competing process and the size and complexity of the body panel. Large panels and panels with simple geometries are best for steel stamping.

Injection molded engineering thermoplastics are competitive with SMC only when the body panel application is both small and complex. Unless the prices of typical engineering thermoplastics are reduced, they will not be cost effective for use in large simple panels.

However, the purpose of building cost models is to eliminate the dependence on generalizations or "rules-of-thumb". The preceeding observations are offered *caveat emptor* (let the buyer beware).

CONCLUSIONS

The conclusions of this paper fall into two categories: specific and general. Specific conclusions apply only to the cost estimate of the hypothetical hood. General conclusions apply to the cost modeling methodology.

Drawing specific conclusions from a cost estimate can be misleading, because each estimate is no better than the input assumptions from which it is derived, and because there are no universally correct input assumptions. However, if one accepts the assumptions outlined in this report, the following can be demonstrated regarding the cost of fabricating a 25 pound SMC hood.

1. Low profile SMC sheet can be produced at a cost of $0.53 per pound. Ninety percent of this cost is due to the constituent materials.
2. The cost of molding a 25 pound SMC hood is $24.22, excluding finishing, rework, and rejection costs.
3. The cycle time for molding a 25 pound hood without in-mold coating is 129 seconds. The sensitivity of cost to changes in the cycle time has been established (Figure 1).

More broadly, the cost model described in this report can and is being used to help management, engineering, and design make better decisions. When compared with the more traditional "back of the envelope" approach, cost modeling is more precise and probably quicker. Compared with the "feedback loop" approach, in which a dedicated cost analysis group feeds estimates back to the designer, cost modeling is much more efficient.

The technical cost models developed at the Materials Systems Laboratory at MIT are being used in industry for purposes of strategic planning, advanced engineering, and design support. In most of these cases, the use of cost models has constituted a quantum leap above established practice.

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