THE HANDBOOK OF MANUFACTURING ENGINEERING
Second Edition

Factory Operations

Planning and Instructional Methods

EDITED BY
Richard Crowson

Taylor & Francis
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Preface

Handbooks are generally considered to be concise references for specific subjects. Today's fast-paced manufacturing culture demands that such reference books provide the reader with how-to information with no frills. Some use handbooks to impart buzzwords on a particular technical subject that will allow the uninitiated to gain credibility when discussing a technical situation with more experienced practitioners.

The second edition of *The Manufacturing Engineering Handbook* was written to equip executives, manufacturing professionals, and shop personnel with enough information to function at a certain level on a variety of subjects. This level is determined by the reader.

The second edition of this handbook is divided into four main sections on issues that face the mechanical engineer as he or she attempts to learn the process of manufacturing. The progression from product and factory development, factory operations, parts fabrication, and assembly processes is a natural progression of information for one learning how a product flows through a manufacturing facility.

A manufacturing engineer is expected to be a problem solver and a person who is capable of working closely with all involved departments to resolve issues and improve designs on a daily basis. The manufacturing engineer is also challenged with the task of improving products and facilities to make the entire process more efficient.

As a manufacturing engineer uses this handbook to study history and apply principles to an existing manufacturing firm, new ideas will be spawned that will allow improvements in process flow and product flow. The successful efforts of many years' experience are captured in these chapters and can be used profitably by any reader willing to think out of the box when facing challenges on a daily basis.

Volume II of this book focuses on the role of the manufacturing engineer as a key component of the operation of the factory. Planning and instruction in the factory fall to the manufacturing engineer. This is the reason that detailed descriptions of successful methods are presented in this section.

As many manufacturing engineers develop firsthand knowledge of engineering principles, some will accept positions as design engineers or managers of design engineering.

This book and the knowledge gained as a manufacturing engineer will serve as a reminder that designing something that is not properly communicated to the fabricators and assemblers will never achieve the design goals desired. The manufacturing engineer may change titles and blend responsibilities, but will always be a manufacturing engineer at heart, if the goals of design and manufacturing are merged.

RICHARD D. CROWSON,
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Editor

Richard D. Crowson

Richard Crowson is currently a mechanical engineer at Controlled Semiconductor, Inc., in Orlando, Florida. He has worked in the field of engineering, especially in the area of lasers and in the development of semiconductor manufacturing equipment, for over 25 years. He has experience leading multidisciplinary engineering product development groups for several Fortune 500 companies as well as small and start-up companies specializing in laser integration and semiconductor equipment manufacture.

Crowson's formal engineering training includes academic undergraduate and graduate studies at major universities including the University of Alabama at Birmingham, University of Alabama in Huntsville, and Florida Institute of Technology. He presented and published technical papers at Display Works and SemiCon in San Jose, California.

He has served on numerous SEMI task forces and committees as a voting member. His past achievements include participating in writing the SEMI S2 specification, consulting for the 9th Circuit Court as an expert in laser welding, and sitting on the ANSI Z136 main committee that regulates laser safety in the United States.

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Contents

1 Practical Cost Estimating for Manufacturing

John P. Tanner

Editor's note: This chapter was condensed from a book manuscript prepared by John P. Tanner. The editor wishes to thank Mr. Tanner for generously allowing use of this material.

1.0 INTRODUCTION TO COST ESTIMATING

The manufacturing cost estimate is the key in new or follow-on business acquisition and the continued growth of the company. It must be built around a sound, well-thought-out manufacturing plan. It must address the cost of facilities, equipment, tooling, materials, and support labor, as well as direct labor to actually fabricate and assemble the product. The estimate must be responsive to customer delivery requirements and production rates, and reflect manufacturing a product of the desired quality and reliability. The cost estimate is a prediction of what the product will cost to manufacture at some future point in time. Estimating is not an exact science, yet a good cost estimate will come very close to actual costs incurred. The accuracy of any cost estimate depends on:

1. The time allocated for the preparation of the estimate
2. The knowledge and skill of the estimator
3. The depth and completeness of preproduction planning
4. The amount of product description information available
5. The accuracy of the material estimate

The higher the percentage of labor cost in the estimate, the greater is the need for precise labor standards. If engineered standards or estimated standards are not available, the estimator must use historical data and his or her own judgment, experience, and knowledge to develop the labor estimate (see also chapter 4 of this volume, "Work Measurement").

In many products, material and subcontract costs can be as much as 70% of product cost. This means that these costs must be examined very carefully at the time the manufacturing cost estimate is prepared. For best results, direct quotes should be obtained from suppliers and subcontractors. Time constraints in completing the cost estimate may not allow sufficient time to solicit these quotes, forcing the use of historical cost data for the same or similar parts and materials, factored for inflation and anticipated cost growth.

Once the basic estimates of labor hours and material dollars have been put together, the judgment exercised in determining the initial costs and the rate of improvement to achieve the eventual cost will have a major effect on the final accuracy of the estimate. An important part of the estimator's job is to prevent ill-advised management decisions by making certain that the methodology, assumptions, and ground rules are understood. Management must look beyond the estimate and consider a bigger picture than the cost estimates at hand, but should understand the risks associated with arbitrary changes to a well-prepared manufacturing cost estimate.

Figure 1.1 shows the basic structure of a manufacturing cost estimate. The sum of direct labor and direct material is known as prime cost. When prime cost is added to manufacturing overhead, we obtain factory cost, or cost of goods manufactured. Total product cost, then, is the sum of selling expense, general and administrative expense, development cost, and factory cost contingencies. The addition of profit yields the price to the customer.

The problems encountered in developing a sound manufacturing cost estimate can be many; however, they can usually be categorized into the following seven categories:

1. Inadequate data on which to develop the cost estimate
2. Inadequate staff and time to prepare the estimate
3. Poor estimator selection
4. Careless estimating
5. Optimistic estimating
6. Inadequate preproduction planning
7. Management inertia

The seven problem categories are not listed in order of importance. Any one or several can be critical to the development of a sound manufacturing cost estimate, depending on the circumstances and the situation that prevails at the time.

The cost estimator may be a manufacturing engineer, an industrial engineer, or a manufacturing technical specialist with heavy experience in the manufacturing technology in which he or she is preparing cost estimates. Cost estimating is highly demanding work, often requiring extended overtime and short deadlines. It requires the ability to quickly formulate a preproduction plan, and to visualize work flows, equipment, and tooling. A labor estimate that comes close to actually incurred costs must then be accepted by management. Not only must this be done under considerable pressure, but it must handle last-minute changes to the requirements the estimate was built on, as well as management-directed changes. In many large companies, an independent cost estimate may be developed by the fiscal or marketing groups, and is used as a check against the more detailed analysis described in this chapter.

1.0 PROGRAM REQUIREMENTS

Program strategy and objectives. What are the issues? What needs to happen? What is the critical path? What are the assumptions and ground rules? Who is the customer? Is co-production involved? If so, what is the split?

1.1 <u>PRODUCT/HARDWARE</u>

Product definition. How will it change from concept, through development to production? How will configuration be controlled? Will a technical documentation package be provided? When? To what level? What quantities of deliverable hardware will be provided in development? Pilot production? Production? What about spare parts? Will there be any GFE or CFE?

1.2 <u>PROGRAM TIME PHASING</u>

When will the program start? Development? Pilot production? Production? What are the key program milestones? What are anticipated peak production rates? When will they occur?

1.3 <u>PROGRAM CONSTRAINTS</u>

Potential problem areas and risks. New or advanced manufacturing processes and technologies. Unusual inspection, testing, or acceptance requirements.

2.0 <u>DEVELOPMENT PLAN</u>

What will be accomplished in the development program? What deliverable hardware will result? Engineering built? Manufacturing built? How will producibility and DTUPC be addressed? How will the hardware change as it evolves through the development cycle?

3.0 <u>MANUFACTURING PLAN</u>

Fabrication and assembly sequences and flows. Estimated times. Equipment requirements. Tooling requirements. Overall block layouts. Space required. Manufacturing flows. Processes.

3.1 <u>MAKE OR BUY PLAN</u>

What is the rationale for the make or buy plan? Identify major items to be subcontracted.

3.2 <u>TOOLING PLAN</u>

Tooling philosophy. Tooling requirements. Is interchangeability a requirement? Will tooling masters and gages be required? How will tooling differ from development to pilot production to production? Will tooling be design tooling, shop aid tooling? Will NC be used? How will tools and tapes be controlled?

3.3 <u>MANPOWER PLAN</u>

Skills requirements. Availability of manpower. Projected manpower needs of program. Anticipated training requirements. Support personnel needs.

4.0 <u>FACILITIES PLAN</u>

Identify new or additional equipment needed and estimated cost. Additional or existing building floor space requirements and estimated cost. Would include engineering, lab, manufacturing, test, storage, bunker, and special process area. Identify any requirements for special or unusual facilities such as clean rooms, dark rooms, specially reinforced floors, ESD protection, etc. Provide estimated cost and time when facilities would be needed.

FIGURE 1.1 Structure of a cost estimate for a manufactured product.

5.0 MATERIAL ACQUISITION PLAN

Identify long lead items, source selection plans. Who are major subcontractors and how will they be controlled and managed? What are plans for stores and kitting of material? What are the plans for dual sourcing? What is the material handling plan for receiving, stores, staging for production? How will vendor and subcontractor follow-up and expediting be accomplished to ensure on-schedule delivery of material? How will engineering changes and shop overloads be handled?

6.0 SCHEDULES AND TIME-PHASING

6.1 PROGRAM MILESTONE SCHEDULE

Overview schedule of entire program showing all phases with key milestones and events, including follow-on work. Should show development, procurement, facilities, production, etc.

6.2 DEVELOPMENT SCHEDULE

Key events in engineering and development, in sufficient detail to clearly portray development time-phasing.

6.3 MANUFACTURING SCHEDULES

Initial low rate production and full production. Manufacturing buildlines, block release plan.

6.4 PROCUREMENT SCHEDULE

Long lead and subcontract deliveries. Should show entire procurement cycle from requisition through order placement to material kitting and issue from production.

6.5 FACILITIES AND EQUIPMENT SCHEDULE

Must show all key milestones for new equipment and facilities acquisition, including order placement, ship date if equipment, ground breaking if new construction, through to available for production use date.

7.0 QUALITY ASSURANCE PLAN

What is the inspection and test plan for the product? What specifications and standards will apply? How will vendor and material quality levels be maintained? What is the plan for the rework and/or disposition of discrepant hardware?

8.0 NEW MANUFACTURING TECHNOLOGIES

Describe new manufacturing technologies associated with the program and plans for training and qualification in production, including equipment and process shakedown and debug. How and when this will be accomplished ahead of the production phase?

FIGURE 1.1 (Continued)

The cost of preparing the estimate must be borne by the company whether it results in new business or not. Most new contracts for manufactured products are awarded based on lowest cost, best delivery, and quality of the product, not necessarily in that order. Management must decide the “win probability” on any estimate for new business, and from that decide the effort to be expended in preparing the cost estimate. It may even decide not to submit a bid. Management should prepare a bid strategy and plan that includes reviews at critical stages in the preparation of the cost estimate. There are several good reasons for this:

1. Basic errors or omissions can be found and corrected before the estimate goes beyond the preliminary stage, when changes would be costly and time consuming.
2. The preliminary estimate may be sufficient to satisfy the requirements, and early management review ensures that no further cost estimating effort will be authorized beyond the preliminary stage.
3. Management review brings the best minds and talent available in the company to bear on the manufacturing cost estimate, serving as a check on the estimate and its assumptions.

Constraints of time and cost often leave no opportunity to explore and verify many of the premises and the assumptions used in preparing the estimate. In spite of this, cost estimates for manufactured products are prepared every day that accurately reflect manufacturing costs for the product and are truly competitive in bringing in new business for the company. In the following subchapters, the steps required to prepare a manufacturing cost estimate that is both accurate and competitive are explained. Examples and cost estimating data in practical form are also provided to help in preparing estimates.

1.0.1 Bibliography

Tanner, J.P., *Manufacturing Engineering: An Introduction to the Basic Functions*, 2nd ed., Marcel Dekker, New York, 1991.

1.1 UNDERSTANDING THE ESTIMATE REQUIREMENTS

1.1.1 Determination of Cost Estimate Requirements

In any engineering work, the solution is usually readily apparent once the problem is fully defined. The same holds true in cost estimating for manufacturing. If the cost estimate requirements are known and fully understood, preparation of the estimate is usually routine. To do this requires answers to the following questions:

1. Who is the prospective customer?
2. What is the bid strategy?

3. What are the requirements?
4. What are the assumptions and ground rules?
5. Is the product to be manufactured fully defined?
6. What are the potential problem areas and risks?
7. What are the key milestones, delivery requirements, and production rates?

Type of Solicitation

The type of solicitation is important in the formulation of a bid strategy, and in deciding the resources that will be committed to preparing the manufacturing cost estimate. A quotation for an additional quantity of parts to a current customer is one example. A quotation for a newly designed item, which has never been built in production before, is quite a different matter if your company is one of several submitting bids. Firms in the defense industry, whose primary customer is the government, can survive only by winning contracts awarded to the lowest bidder among several submitting bids. This winning bid must be supported by a detailed and valid cost estimate. Figure 1.2 shows the outline for a production program plan used by an aerospace company as the basis for its cost estimate and proposal to the government. Such an outline forces consideration of all the requirements.

The majority of manufacturing cost estimating involves job-order production in the metalworking and allied industries in the United States and the rest of the Western world. Castings, forgings, formed and machined parts, and assemblies are produced by thousands of small and medium-sized firms to exacting specifications within the limits of the estimated cost. Solicitations are usually "firm fixed price," which means that if the cost estimate is in error on the low side, the difference is absorbed by the company.

A high estimate may mean extra profit for the company, or it may mean that the contract is awarded to another firm whose price was more in line with what the item should cost. On bids for an additional quantity of the same or a similar item ordered previously, customers will often expect a price reduction because of the learning

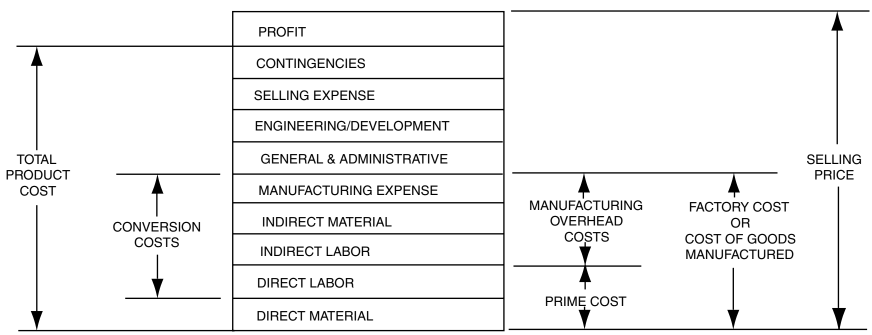


FIGURE 1.2 Production program plan checklist.

curve effect, which implies continuous cost reduction the longer the product remains in production (see Subchapter 1.4).

Product or Hardware to Be Delivered

Adequate product definition is critical to developing a meaningful manufacturing cost estimate. This may include a set of engineering drawings that fully describes the product or parts to be produced. In many instances, shop process or routing sheets and sample parts are available. The product may currently be in production. Should this be the case, it is a relatively easy matter to determine the sequences of manufacture.

If the drawing package describes a product that has never been built in your plant before, a different approach is required to develop a sound manufacturing cost estimate. The drawing package must be broken down into piece parts, subassemblies and assemblies, and a parts list constructed. This will show (in the case of an assembled product) how the assembly goes together and will form the basis for the bill of material and the fabrication and assembly processes.

There are differing levels of detail and description provided by product technical-data packages. Drawing packages may show the lowest level of technical detail down to the smallest piece part and assembly, each on a separate drawing. Other engineering drawings provide a minimum of detail, showing assembly and detail parts on the same drawing. Engineering drawings and other technical documentation cost money to prepare and to update with the latest changes. Technical documentation packages provided to bidders for cost estimates and quotations do not always fully and correctly represent the product. There may be errors in dimensioning and tolerancing that were noted the last time the product was manufactured, but these changes were never picked up and documented by formal engineering change orders to the drawings.

Many times in bidding the product as depicted in the engineering drawing package, Defense Department contractors, with no other product data or knowledge to go by, have seriously underbid production contracts on hardware and systems designed by other contractors simply because all the information needed to fabricate and assemble the product was not shown on the drawings. In preparing a manufacturing cost estimate, every effort should be made to make certain that the drawings are current and that all engineering change information is included.

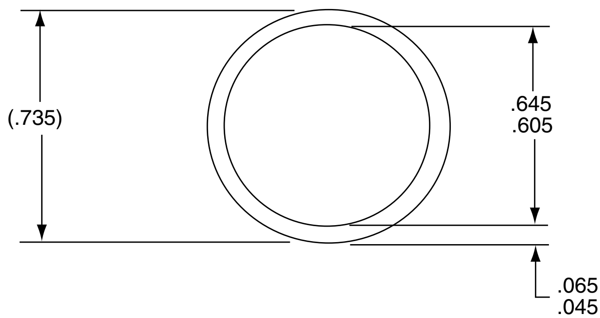
Engineering drawings must often be supplemented by manufacturing engineering documentation such as process routings, methods sheets, visual aids, tool drawings, test procedures, and process specifications to determine what is really required to manufacture the product. If possible, this documentation should be provided by the prospective customer as part of the bid package. If your company is submitting a cost estimate for the manufacture of a build-to-print product that you have never produced before, it is imperative that whatever shop-process documentation that exists be obtained to aid in developing the cost estimate. If not available, the bidder may have to prepare preliminary documents in order to form the basis of a bid.

Definition or Concept

The estimator must work with many kinds of drawings, specifications, and shop documents. Included will be specification control drawings similar to Figure 1.3, which clearly spell out all critical parameters of the jacketing material for a cable assembly, and may list approved or qualified sources for this material. Figure 1.4 shows a typical detail or fabricated part drawing for a 0.020-in. thick gasket which would be stamped with a die. A typical assembly drawing is shown in Figure 1.5, for a voltage regulator assembly. Notes on such a drawing might include:

1. Prime and seal threads using Loctite
2. Torque fasteners to 3 to 5 in.-lb.
3. Ink stamp assembly number as shown

Column A in the parts list shows the number of items per assembly, column B is the part number, column C is the item name, and column D is the find number shown in the leader arrows on the drawing.



NOTES- UNLESS OTHERWISE SPECIFIED

1. MATERIAL: SILICONE RUBBER CONFORMING TO ZZ-R-765, CLASS 2A OR 2B, GRADE 50, WHITE.
2. IDENTIFY PER MIL-STD-130 WITH MANUFACTURER'S PART NUMBER AND FSCM NUMBER; CONTROL NUMBER ENCLOSED IN PARENTHESIS; BAG AND TAG.
3. SHAPE AND CONCENTRICITY: ID AND OD SHALL BE NOMINALLY CONCENTRIC WITH A UNIFORM WALL THICKNESS. JACKET MAY BE ELLIPTICAL IN FREE FORM EXCEPT OPPOSING SURFACES SHALL NOT ADHERE TO EACH OTHER.
4. LENGTH SHALL BE FURNISHED CONTINUOUS AS SPECIFIED (10 FEET MINIMUM).

FIGURE 1.3 Specification control drawing (SCD) for a hig-reflectance silicone cable jacket.

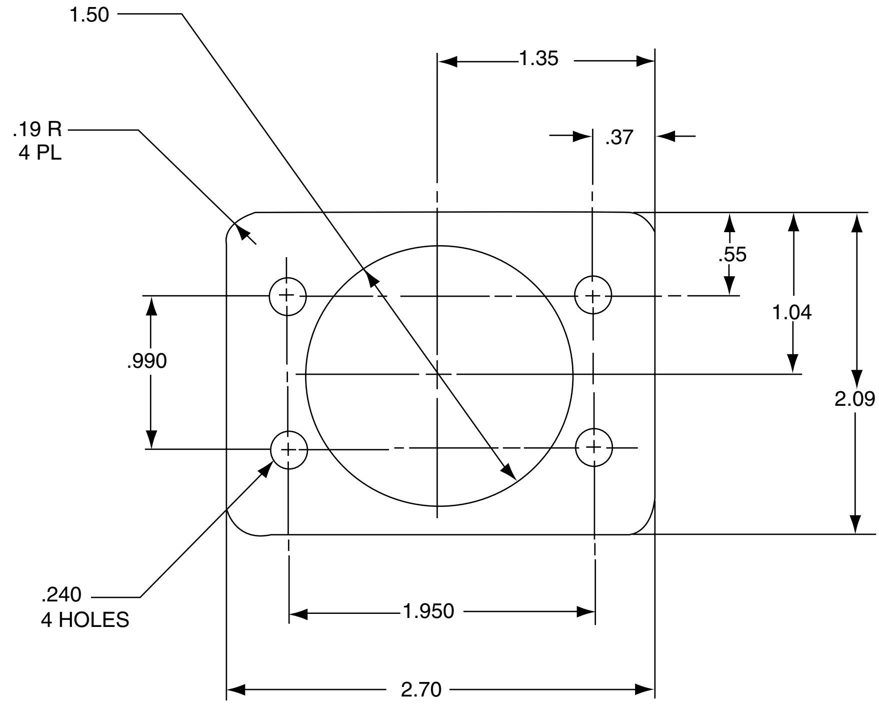
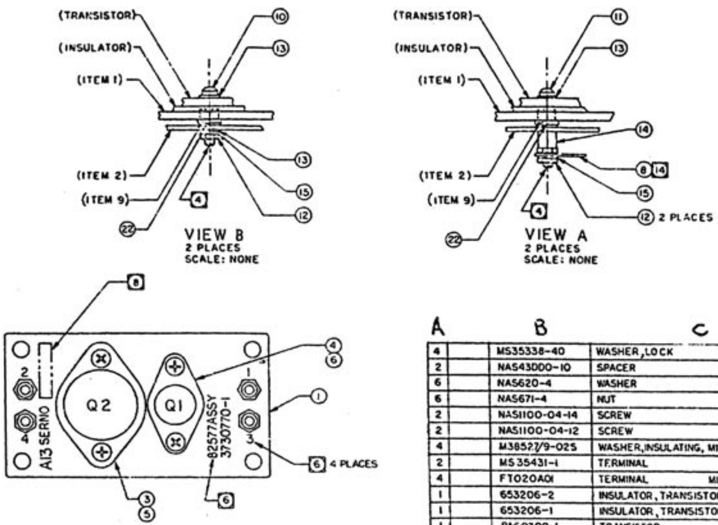


FIGURE 1.4 Gasket made from 0.020-in. material.



A		B	C		D
4		MS35338-40	WASHER, LOCK		15
2		NAS43DD0-10	SPACER		14
6		NAS620-4	WASHER		13
6		NAS671-4	NUT		12
2		NAS1100-04-14	SCREW		11
2		NAS1100-04-12	SCREW		10
4		M38527/9-025	WASHER, INSULATING, MIL-M-38527/9		9
2		MS35431-1	TERMINAL		8
4		FT020A01	TERMINAL MIL-T-55155/2		7
1		653206-2	INSULATOR, TRANSISTOR (9)		6
1		653206-1	INSULATOR, TRANSISTOR (9)		5
1		PA60309-1	TRANSISTOR (13)		4
1		JANTX2N5038	TRANSISTOR MIL-S-19500/439		3

FIGURE 1.5 Voltage regulator assembly.

Often it becomes necessary to estimate the cost to produce an item that is not yet fully designed. Such estimates are made from sketches, concept drawings, or design layouts. Preparation of these estimates requires the estimator to fully understand the design concept envisioned by the designer. It is not uncommon for such preliminary designs and preliminary bills of material to grow by as much as 40% in complexity and parts count by the time the final manufacturing drawings are released. Figure 1.6 shows a design layout for a mortar round that, once fully designed, developed, and qualified, would be produced in high volume for the army.

Delivery Requirements

The estimator must know if the customer's delivery schedule can be met, considering the lead time required for planning, tooling, and obtaining the necessary parts and material, plus the number of days to actually manufacture the product. Analysis of the delivery requirements determines peak production rates, and whether one or two shift operations are needed. Perhaps the required delivery rate can be met only by extended overtime. All of these elements affect cost.

Analysis of shop flow times, material lead times, capacity of shop machines, and shop and machine loads in the time period the proposed work would be performed can be crucial in developing any manufacturing cost estimate. A firm may manufacture to stock or inventory, based on a sales forecast. This offers the advantage of smoothing the shop workload and being able to plan well in advance for manufacturing operations. Delivery requirements requiring higher rates of production may require more units in work in a given time. This allows better labor utilization and production efficiency. This has to traded off against the cost of carrying inventory, as

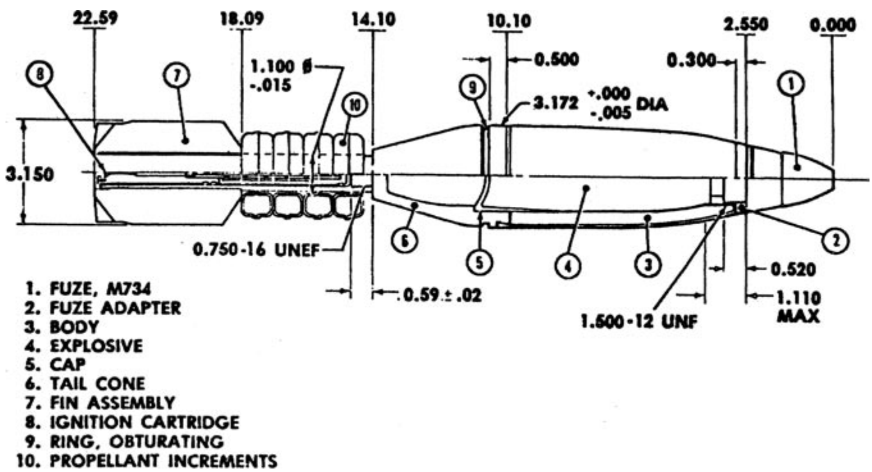


FIGURE 1.6 Design layout for a new mortar round.

opposed to delivering for payment upon product completion. Lower production rates result in smaller lot sizes, increasing the number of setups for the same number of units. This lowering of production rates can have a profoundly adverse effect on the attainment of projected improvement curves. Setup and teardown caused by small production lot sizes should be avoided as much as possible.

Special Provisions

A contingency factor should be applied to any manufacturing cost estimate in which the product is not fully defined or is still undergoing change. The amount of contingency is a judgment call which would:

1. Vary with the stage of product development
2. Depend on the newness of the program, the market application area, the technology, the industrial processes, and the organization
3. Depend on the time allowed for development
4. Consider the degree of development required
5. Vary with the general economic conditions

Figure 1.7 shows a contingency policy used by a large manufacturer of computers and point-of-sale terminals.

In addition to the importance of product definition, a complete bill of material or engineering parts list is vital to estimating manufacturing costs. This must be carefully reviewed, and the make-or-buy decisions for pricing purposes made. The make-or-buy plan determines the form the estimate will take and establishes the basis for material pricing, labor content estimate, and the long-range impact on facilities and capital equipment.

In government contracts there may be special provisions for placing work with small or minority businesses in economically depressed areas, or clauses that parts or materials can be obtained only from government-qualified sources. Careful attention should be given to such provisions specified in the request for quote when formulating a bid strategy.

“Understanding of estimate requirements” implies that management and the estimator understand all new processes and manufacturing technologies that may be introduced if the job is won. The costs that are associated with training, technical support, safety, toxic waste handling and disposal, etc. can be substantial and should be recognized. Such costs may force companies with limited resources to go outside for these products and services.

1.1.2 Estimate or Bid Proposal Strategy

Formulation of a bid or pricing strategy follows a thorough understanding of the requirements. Such a strategy would consider the probability of winning the job when competition is involved or when no competition is involved. Marketing intelligence concerning the prospective customer and the competition will be a major

PHASES OF COST ESTIMATE	CONTINGENCY GUIDELINES AS % OF MLB
I. ENGINEERING DESIGN GOAL	30 – 50%
PRELIMINARY DESIGN "A" MODEL AVAILABLE IF REQUIRED	
II. ENGINEERING	20 – 30%
"B" MODEL IN FABRICATION PRELIMINARY B/M AVAILABLE PARTIAL DRAWINGS AVAILABLE	
III. PRELIMINARY PRODUCTION	10 – 20%
"B" MODEL TEST COMPLETED AND ACCEPTED MANUFACTURING B/M AVAILABLE MAJORITY OF DRAWINGS RELEASED	
IV. PRODUCTION	0 – 10%
B/M COMPLETE COMPLETE DRAWING PACKAGE AVAILABLE SPECIFICATIONS RELEASED	

Note: MLB=Material, Labor and Burden

FIGURE 1.7 Contingency policy.

factor in developing the bid or estimate strategy. "Win probability" determines the number of company resources that will be devoted to preparing the cost estimate. A low win probability could only justify a minimal investment of resources, or a no-bid decision.

The bid strategy defines the rules and guidelines to follow in formulating a tooling philosophy, spelling out ground rules and assumptions, assigning personnel, and determining how close to shave the final price quotation. The bid strategy should then be made known to the estimators and all key people involved in preparing, reviewing, and approving the cost estimate. It will be the baseline for preparing and issuing a proposal authorization, or directive, specifically spelling out who is going to do what and when. Such a proposal authorization or directive should contain the following information as a minimum.

1. What is to be bid, and who is to do what in preparing the cost estimate
2. A time-phased plan or schedule for preparing the estimate
3. A list of ground rules and assumptions

4. A make-or-buy plan
5. Specific description of any special provisions contained in the request for quote from the customer
6. The specifications that apply to the estimate, and in case of conflict, which takes precedence, the drawings or the specifications
7. Peak production rates that processes, equipment, tools, and facilities must be able to support

The cost estimators now have a well-thought-out and well-researched plan to follow, and management is providing the necessary leadership and direction to reach the goals determined to be advantageous for the manufacturing cost estimate at hand.

1.1.3 Estimate or Proposal Plan, and Time Phasing

It seems that there is rarely sufficient time to prepare the manufacturing cost estimate. The customer wants a response within days or even hours after requesting price and delivery, and management must have time to review and approve the cost estimate. This often creates a situation requiring long hours of overtime and much pressure on the estimating team. Temptation is strong to provide expedient answers and estimates that cannot be supported when analyzed in depth by management and supervision.

There should be a proposal or cost estimate schedule plan that highlights the critical milestones in the estimate preparation and review, and maximizes the available (limited) time that is allocated for this purpose. Figure 1.8 shows such a plan for an aerospace product. This represents a minimum plan. Where time is very limited, such as a few days to a week, the plan must be much more detailed, covering the actual steps in estimate preparation and review.

Resources to Be Allocated

A key decision of how much time and money to invest in preparation of the manufacturing cost estimate is required, since this investment may not result in winning the new business. A cost estimate for a manufactured product can be used for a number of reasons other than to establish the bid price of a product for quotation. These include:

1. To verify quotations submitted by vendors
2. To determine whether a proposed product or item can be manufactured and marketed profitably
3. To provide the basis for a make-or-buy decision
4. To determine the most economical methods, processes, tools, or materials for a manufactured product
5. As an aid in evaluating design alternatives
6. To determine whether to bid

Preparation of the cost estimate will also aid in the determination of resources to be finally expended in its preparation. One criterion used to determine the resources

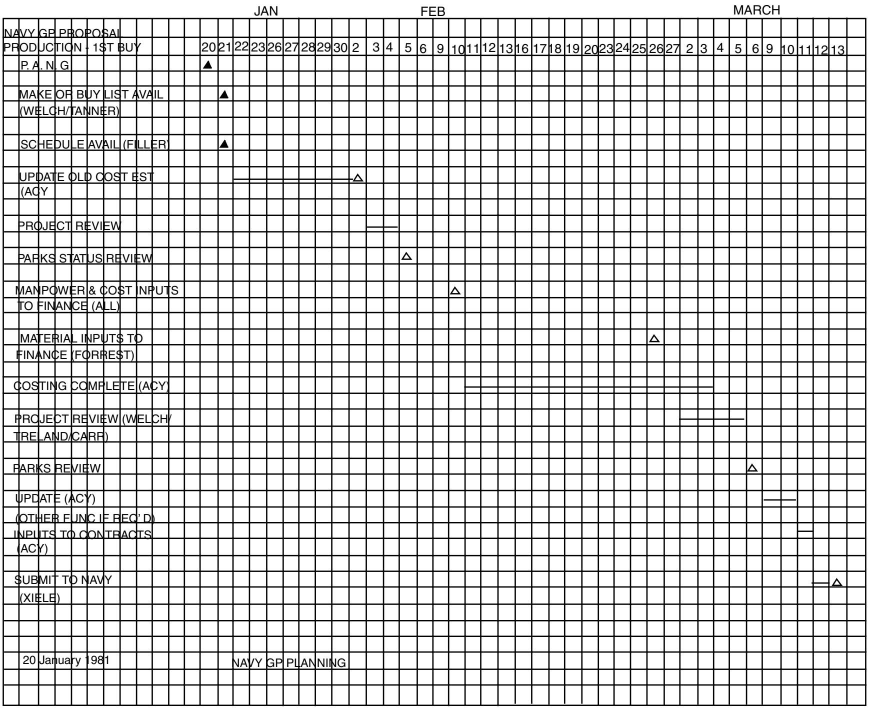


FIGURE 1.8 Cost estimate preparation plan.

to be expended in cost estimate preparation is the value of the new business acquisition. Management may review a preliminary estimate and decide that no further time or effort should be expended. The preliminary estimate is deemed sufficient to satisfy the requirements.

Proposal or Estimate Milestones and Schedule Plan

Key events in preparation of the estimate should be listed, and a time span assigned for accomplishment. Key milestones for most cost estimates of a manufactured product include:

Availability of engineering drawings and specifications
Completion of the engineering parts list and the manufacturing bill of material
Preparation of the make-or-buy plan
Completion of the listing of needed shop equipment and facilities
Completion of the preproduction planning
Preparation of the listing of needed shop equipment and facilities

Preparation of the tool list
Identification of long-lead procurement items
Completion of material and subcontract pricing
Completion of manufacturing labor estimate, including support labor
Completion of the total manufacturing cost estimate
Scheduled estimate checks, reviews, and approvals
Final pricing and costing
Submission to the prospective customer

Figure 1.1 shows other milestones, some of which may not be needed at all. In a small shop, the owner may have a relatively simple product line, allowing him or her to estimate the cost of new business with some degree of accuracy. The owner must make certain that he or she fully understands the bid requirements, and must cover the same proposal milestones as the larger organization, even though he or she does so in a less formal manner.

Management Control and Estimate Transmittal

As I.R. Vernon, in *Realistic Cost Estimating for Manufacturing* (1961), points out:

> Fast, economical and accurate estimates require proper management control of the estimating function. Management establishes the type of estimating department that will best serve company needs, and then formulates the procedures and administrative controls necessary for efficient departmental operation.

Such controls include the screening of incoming requests for bids or estimates, usually by a committee of top managers, to make the bid–no-bid decision. If the decision is to bid, they set up the proposal schedule plan, assign personnel and resources to prepare the cost estimate, and establish the administrative routings and controls for review and approval.

An essential management control of the cost estimating function is the identification and analysis of previous estimate cost deviations versus actual costs. Records of these deviations should be maintained and plotted to determine trends and to pinpoint areas of weakness in the cost estimating function. There may be many reasons for cost estimates that are too high, too low, or simply unrealistic. One of the first areas to examine is arbitrary cuts or reductions made by management, or unrealistic contingency factors applied to an otherwise sound cost estimate which results in others winning the award. Other reasons that estimates are too high include:

1. Being deliberately high to discourage business the company does not want
2. The tendency to be overly cautious with new products, processes, technologies, etc. that the estimator is not familiar with or does not understand
3. Preproduction planning that calls for more processing steps or more sophisticated tooling than is actually required
4. Poor material pricing practices, such as failing to consider price breaks on quantity purchases of material

5. Overestimating labor costs by assuming higher-than-normal start-up costs, a shallower learning curve slope than would actually be incurred, or by using loose labor standards in building the estimate

High estimates sometimes result in greater profits than anticipated, but may also lose business that could have been profitable. Other problems caused by high estimates are loss of customer goodwill, greater investment of resources in cost estimating because more estimates must be processed to book a smaller volume of work, and eventually being priced out of the market.

Some of the more significant reasons for low cost estimates include:

1. Incomplete or incorrect product design information, or a new design that "grows" after the estimate, in parts count, in complexity, and in design changes that occur after the production cycle has started
2. Higher labor costs than anticipated, possibly due to delays that resulted in production stoppages, higher-than-anticipated rework due to design or tooling problems, or poor planning in the preproduction phase
3. Higher material costs than anticipated, due to such factors as unplanned material price increases, design changes that cause material requirements to change, and higher-than-planned scrap and line losses

How the Estimated Should Be Transmitted

When the cost estimate for a manufactured product is transmitted to the potential customer, it should always be by written quote or other formal means of transmittal. The price and delivery may be given verbally, but should always be followed with the confirming written quote. The formal quotation should list and explain all assumptions and contingencies, and for how long a time the price given in the quotation is valid.

Qualifications and Caveats

The transmitted price and delivery quotation should always be given in a manner that is responsive to the customer's request for price inquiry. For example, if the price quotation is a bid on government work, specific cost breakdowns, usually by work breakdown structure, are requested in addition to end-item price and delivery. Failure to provide this breakdown results in a nonresponsive proposal.

Cost estimates that are developed by companies that do business with the government often require a government audit before a final contract award. Such audits can be very upsetting for the company and the estimating department that does not have good records, cannot show step by step how costs were developed in the estimate, or cannot show actual price quotations for major items to be purchased outside.

Final Price Negotiation

In most instances, the price and delivery quoted are either accepted by the customer, or the work is done by someone else. There is no final price negotiation. On the other hand, the larger the job in total dollar price, and the longer the production run, the more likely there will be a negotiation price. In such negotiations, profit margins and contingencies may be reduced in order to obtain the job. The estimated cost to actually do the work should never be part of the negotiating process.

The negotiating process is beyond the scope of this chapter, but it requires the best talent the company has in management and in cost estimating. They must have sufficiently detailed knowledge of the cost estimate and how it was prepared, be able to answer any questions, and face up to any challenge that is presented. A successful negotiation should result in a contract award very close to the price and delivery presented before the negotiations began. Additional negotiations may occur after contract award should there be a change in work scope, such as accelerated delivery, or an increase in number of units to be produced.

1.1.4 Bibliography

Vernon, I. R., *Realistic Cost Estimating for Manufacturing,* Society of Manufacturing Engineers, Dearborn, Michigan, 1961.

1.2 DEVELOPING THE MANUFACTURING PLAN

1.2.1 Review of Product Requirements

The manufacturing cost estimate must begin with a manufacturing plan. The thoroughness and accuracy of this plan determines to a large measure how good the estimate will be. The cost estimator must be able to concept a workable manufacturing plan for any product the firm manufactures. Such a plan must begin with an understanding of the product requirements.

As the cost estimator goes through the drawing package to do the preproduction planning, or what we know as the manufacturing plan, producibility problems may be apparent. In such cases, the problem should be noted, and if time permits, a cost trade study should be initiated. This is to determine if the desired change would generate sufficient savings to offset the cost of making the change. Producibility changes that take place after the drawings are released may not be as attractive as they appear initially, after the impact on schedule, tooling, retrofit, and the cost to change the engineering are all considered.

A checklist for reviewing producibility of an electronics product or assembly represents the kind of questions the cost estimator should be asking as he or she goes through the drawing package:

1. Does the dimensioning facilitate manufacturing, and are the tolerances realistic?
2. Is all marking and stenciling defined and visible?
3. Are assembly notes complete and definitive?
4. Is internal wiring critical? If so, is the location of the wiring specified?
5. Are test points and adjustments accessible?

6. Is harness development required? If so, can the harness be fabricated outside the unit, and installed later as a subassembly? Does the wire run list contain wire length information?
7. Does the design lend itself to mechanized or automated assembly techniques?
8. Does the design avoid the need for select-at-test component matching?
9. Are component parts accessible for assembly? Can all assembly and wiring be done without restriction?
10. Can required testing be performed without disassembling the unit?
11. If wire wrap is used, does the design facilitate automatic assembly?
12. Are standard connectors and assembly hardware used?
13. If circuit card assemblies are installed as part of the assembly, are they designed to plug in, or must they be wired in?
14. Are there mechanical loads such that printed circuit epoxy glass boards are in compression?
15. Has consideration been given to using printed circuit flex cable, or molded ribbon wire cabling instead of hard wiring of the assembly?

As a minimum, the cost estimator should review the drawings of a fabricated product to ensure that they:

1. Are dimensioned and have datum surfaces that are compatible with accepted machining and fabrication practices
2. Have sufficient stock allowances on castings, forgings, and stampings to provide for any mismatch or distortion that may result from heat treating
3. Have maximum allowable tolerances on nonfunctional features and characteristics
4. Have realistic tolerances on functional characteristics
5. Have adequate provision for clamping and locating
6. Provide sufficient clearance and access for the assembly of all component parts
7. Call out standard parts and materials, which can be processed and assembled using general-purpose machines, equipment, and tools

The estimator must next prepare a manufacturing bill of material from the parts list, and the make-or-buy plan that has been established. Next the estimator proceeds to concept the steps and sequences of manufacture for each part, subassembly, and assembly to be made in-house. Then, for each step in the process, he or she determines the machines, equipment, and tools that will be needed. Finally, he or she determines setup and run times for each step or sequence in the manufacturing process.

1.2.2 The Make-or-Buy Plan

Purchased parts and materials, as well as subcontracted items, can account for as much as 70% of manufactured product cost. It is therefore important that the initial make-or-buy analysis be made by a qualified cost estimating professional based on knowledge of the plant capability to manufacture or not to manufacture the items on the bill of material. For example, if the company is primarily an assembly house, then all fabricated and machined metal parts would be classified as "must-buy" items, in addition to hardware and bulk material items such as paints and solvents. Only those items that can be either made or bought will require a detailed analysis from cost and shop load standpoints. In larger companies, a formal make-or-buy committee with key people from all of the functions is chartered, chaired by the senior operations or manufacturing executive. This committee then makes final make-or-buy determinations based on recommendations from all disciplines concerned.

Must-Buy Items

Obvious "buy items" based on shop capability to perform the process of manufacture are the easiest decisions to make. However, management may decide to create the process or capability in-house to have a degree of control not possible when the work is placed outside. If the requirement exists for only a short time, this may unnecessarily commit company resources to a process capability that would stand idle much of the time.

Must-Make Items

There are usually a number of fabrication, assembly, and testing operations on any manufactured product that are critical to its manufacture and performance in the field. These are the operations and processes that must be done in-house to ensure product integrity and control. Such operations usually include product final assembly and test, and fabrication and assembly of close-tolerance or mating parts, among others.

Items That Can Be Either Make or Buy

These items are the ones requiring investigation and analysis prior to the decision to make or buy. Usually decisions on these parts and assemblies are based on cost, promised deliveries, and shop capacity or load. Cost trade studies are made, quotes are obtained from various potential outside sources, and the final make-or-buy decision is made either by senior management or the make-or-buy committee.

1.2.3 Outlining the Manufacturing Sequences and Processes

The operation process chart is the best way to clearly visualize all of the steps in the manufacturing process. This chart depicts graphically the points in the process where materials are brought into the process, and the sequences of all manufacturing, inspection, and test operations. This chart may also contain such detail and information as the standard time for each operation, production equipment and tooling required for each operation, and applicable process specifications.

With the completed operation process chart, the entire process of manufacture can be visualized. The process can then be reviewed and analyzed for optimum sequencing, alternative methods of fabrication, assembly inspection and test, and most efficient methods of production. Equipment and tooling requirements at each step in the flow can be readily envisioned and recorded.

The Operation Process Chart

The principles of operation process chart construction are shown in Figure 1.9. A preprinted chart format is not recommended, because of the wide range of use and application. Symbols used in constructing the operation process chart include:

- F *Operation:* Occurs when an object is intentionally changed in any of its physical or chemical features, is assembled from another object, or is arranged for another operation, inspection, or test
- G *Inspection/test:* Occurs when an object is examined or verified for quantity or quality in any of its characteristics

All steps should be listed in proper sequence for each part or component, working vertically from top to bottom. The major assembly or component is always shown at the far right, and all other components are allotted space to the left of this main component or assembly. The presentation is similar to that of a mechanized

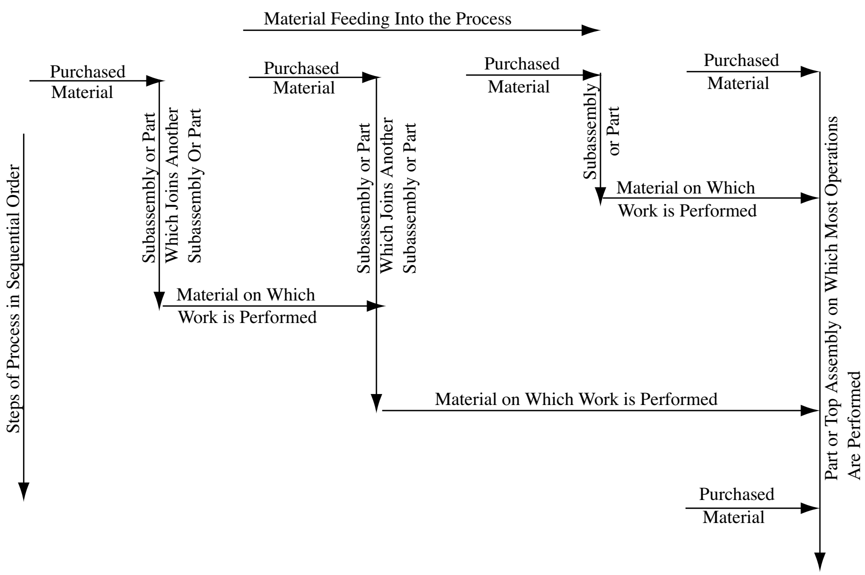


FIGURE 1.9 Principles of construction of an operation process chart.