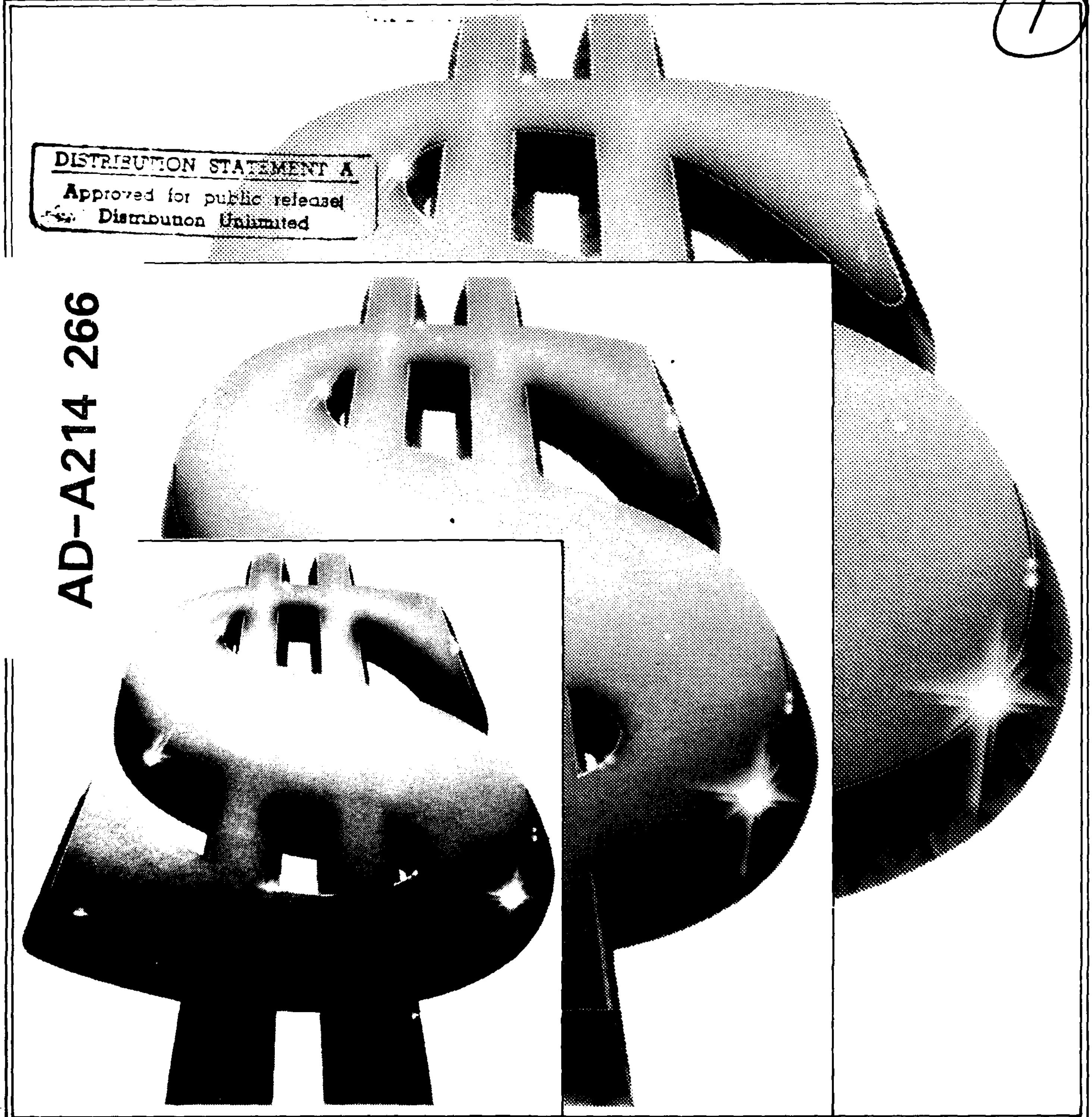
COST REALISM HANDBOOK

FOR ASSURING MORE REALISTIC CONTRACTOR COST PROPOSALS

A HANDBOOK FOR
PROGRAM MANAGEMENT
AND SOURCE SELECTION
PERSONNEL

NAVY OFFICE
FOR
ACQUISITION RESEARCH
WASHINGTON, D.C.
20360



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PREFACE

No longer can the U.S. Government be considered an evergreen money tree, forever offering fruit for unrestricted picking. Just as ecologists are convincing us that our natural resources are not limitless, the Government must convince the world that U.S. Government monetary resources are not inexhaustable. Restraints on Government spending must be enforced, or the United States, long the world's richest nation, will face bankruptcy.

Publication of this guide does not mean the Government is launching a crusade to starve Government contractors. The writers of this guide are firm believers in profit, free trade, and the American economic system. The Government will continue to award contracts and pay costs and fees. Indeed, *this guide represents no establishment of Government policy*, but only an attempt to train direct cost analysts to ensure the Government pays *fair and reasonable* direct costs. We seek to teach beginners in direct cost analysis how to be effective in their work.

"Fair and reasonable" may sound like an ambiguous goal. It is; for no matter what formulas and techniques are used, in the end the costs charged to the Government must represent compromises between the Government and contractor. But these compromises also should be close to the "real" costs the contractor actually will incur--and actually *should* incur.

This guide is not a finger-pointing exercise. We are not chastising contractors for making mistakes; all humans err. Furthermore, recognizing plant inefficiency is not always easy, even when the contractor searches for it. Yet, no matter who is at fault or if anyone is at fault, the Government can save money by identifying overestimates.

This guide was published under Contract N00024-71-C-1382 as the first step in a long-range program being undertaken by NAVSEC 6210. The program's target is more efficient Government procurements, especially military hardware procurements by Department of Defense agencies.

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Section I. ORGANIZATION OF THE GUIDE

In section II, "Getting Acquainted with Cost Analysis," we define direct costs and the other elements of total contract price. We introduce people the direct cost analyst works with, and tell you about responsibilities in cost analysis and contract negotiations. We describe basic concepts and how contractors estimate direct costs.

In section III, "How to Evaluate Direct Cost Estimates," we make you a direct cost analyst--a "technical evaluator" as we call it. Together we analyze the contractor's proposal, backup data, and plant, to determine if his direct cost estimates reflect sound logic and efficient practices. Not only are you responsible for pointing out flaws, you also are charged with noting approval of fair and reasonable cost estimates.

The "Selected Bibliography" contains sources used in preparing the guide. These publications, we feel, are excellent and cover a wide spectrum of topics, and we recommend you read them. We made no attempt, however, to cite all good writings on estimating or analyzing costs. If you know of other good sources, read them.

Terms from the cost expert's vernacular are defined in our "Glossary."

In appendix A, "Experience Curves," we expound on the theories and applications of the experience curve, a useful device for estimating costs at different points in time.

Appendix B, "Evaluating Fabrication: Another Point of View," is a discussion on the fabrication process in which we go into greater detail than we do in sections II and III.

In appendix C, "Systems for Accumulating Cost Data," we discuss contractor cost-accounting systems, focusing on how the diversity of systems affects direct cost estimates and analysis.

We do not presume in this guide to tell you everything about estimating and evaluating direct costs. No rulebooks dictate exactly how contractors must estimate costs, and no guidebook can tell you what to do in every situation. Our aim is to teach you how to react in typical situations--how to think as a direct cost analyst.

AN OBJECTIVE EVALUATION WILL YIELD FAIR AND REASONABLE RESULTS TO BOTH PARTIES – GOVERNMENT AND INDUSTRY.

Section II. GETTING ACQUAINTED WITH COST ANALYSIS

Subsection II-A. THE GAME, THE RULES, AND THE PLAYERS

THE GAME

The contract negotiations "game" is serious business, with an outcome measured in thousands, even millions, of dollars. "Victory" for the Government is a fair total contract price.

First the Government identifies a need for some hardware or service. Then to prospective companies it issues a "solicitation"--either an invitation for bids (IFB), request for proposals (RFP), or request for quotations (RFQ).

In the case of an IFB, companies respond with price bids, and the Government awards the contract to the lowest bidder. Bidders are not required to substantiate their bid prices. Costs are not analyzed. The total price is not subject to negotiation.

In the case of an RFP or RFQ, the contract is awarded primarily on the basis of a company's ability to do the work, as demonstrated by its contract proposal. Price competition becomes the determining factor only when two or more businesses show equal ability to provide the needed product or service. Sometimes, when only one company is considered capable of fulfilling the contract, there is no competition at all; the solicitation is sent only to that company. Such a company is called a "sole-source supplier."

No matter whether RFP's and RFQ's are issued under limited price competition or no competition, the lack of "adequate" competition makes it necessary for responding companies* to supply extensive data to substantiate their proposed prices. All such contractors, even sole-source suppliers, must submit contract proposals telling their plans for fulfilling the contract, the rationale for those plans, and how much

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*More properly called "offerors," we use the common term "contractors" throughout the guide.

it all costs. The Government analyzes the quoted costs and negotiates with the contractor until both parties agree on a total price or agree not to carry through with the contract.

What are the rules of this cost analysis/price negotiations game? What, indeed, are *direct* costs?

THE RULES

Essentially, the rules were just mentioned: When responding to an RFP or RFQ, the contractor must submit, for Government analysis, data that substantiate his cost estimates. He must submit a contract proposal describing the work to be done, the material to be used, how much the labor and material costs, and any other expenses. In addition, either within the basic proposal itself or in backup data accompanying the proposal as part of the "proposal package," the contractor must explain how he estimated his costs. When contract price is expected to exceed $100,000, the contractor must fill out a DD Form 633 and return it to the Government. (See figure II-A-1.)

The Government devised the DD Form 633, "Contract Pricing Proposal," to standardize the breakdown of cost elements by Government contractors. On it, contractors list their total estimate for each cost category, add their profit, and propose a total contract price. It is a helpful tool for the direct cost analyst.

CATEGORIES OF COSTS

"Total price" (line 15, or the "bottom line," on the DD Form 633) is the total amount of money, including "profit or fee," the contractor proposes to charge the Government for fulfilling the contract. "Total cost" (listed on the form as "subtotal," line item 13) includes the expenses *incurred by the contractor* in producing and delivering the end item called for by the contract.

"Profit or fee" (line item 14) usually is figured as a percentage of cost. That is, after a contractor calculates the total cost he will incur in producing a product, he adds to that cost a percentage of the cost itself to allow for his profit or fee. If a contractor determines his total cost for producing a computer is $100,000, for example, and his proposed rate of profit is 10 percent, he would add 10 percent of the computer's cost to the $100,000. The computer's *price* would be $110,000.

DEPARTMENT OF DEFENSE
CONTRACT PRICING PROPOSAL

Form Approved
Budget Bureau No. 22-R100

This form is for use when submission of cost or pricing data (see *ASPR 3-807.3*) is required

PAGE NO.	NO. OF PAGES

NAME OF OFFEROR	SUPPLIES AND/OR SERVICES TO BE FURNISHED
HOME OFFICE ADDRESS	QUANTITY / TOTAL AMOUNT OF PROPOSAL $
DIVISION(S) AND LOCATION(S) WHERE WORK IS TO BE PERFORMED	GOVERNMENT SOLICITATION NO.

COST ELEMENTS	PROPOSED CONTRACT ESTIMATE		
	TOTAL COST[1]	UNIT COST[2]	REFERENCE[3]
1. DIRECT MATERIAL[4] a. PURCHASED PARTS[5]			
b. SUBCONTRACTED ITEMS[6]			
c. OTHER MATERIAL (1) RAW MATERIAL[7]			
(2) STANDARD COMMERCIAL ITEMS[8]			
(3) INTERDIVISIONAL TRANSFERS *(at other than cost)*[9]			
2. MATERIAL OVERHEAD[10]			
3. INTERDIVISIONAL TRANSFERS AT COST[11]			
4. DIRECT ENGINEERING LABOR[12]			
5. ENGINEERING OVERHEAD[10]			
6. DIRECT MANUFACTURING LABOR[12]			
7. MANUFACTURING OVERHEAD[10]			
8. OTHER COSTS[13]			
9. *SUBTOTALS*			
10. GENERAL AND ADMINISTRATIVE EXPENSES[10]			
11. ROYALTIES[14]			
12. FEDERAL EXCISE TAX[15]			
13. *SUBTOTALS*			
14. PROFIT OR FEE			
15. **TOTAL PRICE** *(Amount)*			

I. HAVE THE DEPARTMENT OF DEFENSE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, OR THE ATOMIC ENERGY COMMISSION PERFORMED ANY REVIEW OF YOUR ACCOUNTS OR RECORDS IN CONNECTION WITH ANY OTHER GOVERNMENT PRIME CONTRACT OR SUBCONTRACT WITHIN THE PAST TWELVE MONTHS?

☐ YES ☐ NO *IF YES, IDENTIFY BELOW*

NAME AND ADDRESS OF REVIEWING OFFICE	TELEPHONE NUMBER

II. WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS PROPOSED CONTRACT?

☐ YES ☐ NO *IF YES, IDENTIFY ON A SEPARATE PAGE.*

III. DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT?

☐ YES ☐ NO *IF YES, IDENTIFY.* ☐ ADVANCE PAYMENTS ☐ PROGRESS PAYMENTS *OR* ☐ GUARANTEED LOANS

IV. HAVE YOU BEEN AWARDED ANY CONTRACTS OR SUBCONTRACTS FOR SIMILAR ITEMS WITHIN THE PAST THREE YEARS?

☐ YES ☐ NO *IF YES, SHOW CUSTOMER(S) AND CONTRACT NUMBERS BELOW OR ON A SEPARATE PAGE.*

V. DOES THIS COST SUMMARY CONFORM WITH THE COST PRINCIPLES SET FORTH IN ASPR, SECTION XV (*see 3-807.2(c)(2)*)?

☐ YES ☐ NO *IF NO, EXPLAIN ON A SEPARATE PAGE*

This proposal is submitted for use in connection with and in response to ______________________

______________________ * and reflects our best estimates as of this date,

in accordance with the Instructions to Offerors and the Footnotes which follow:

**DESCRIBE RFP, ETC.*

TYPED NAME AND TITLE	SIGNATURE

NAME OF FIRM	DATE OF SUBMISSION

DD FORM 1 APR 65 **633** PREVIOUS EDITIONS ARE OBSOLETE. S/N 0102-006-0101 C-32487

Figure II-A-1. DD Form 633

Look again at the DD Form 633. "Cost elements" is the heading over the left-hand column, in which 15 "line items" are listed. All line items except "profit or fee" (line 14), "total price" (line 15), and the two subtotals are elements of cost. Cost elements are categories of costs incurred by the contractor; when all cost elements are summed up, the result (line 13) is the total cost incurred by the contractor for producing the end product.

Most cost estimators and analysts classify cost elements generally as either direct costs or indirect costs. *Direct costs* are specifically and uniquely attributable to a particular product or service; if the particular product had not been produced or the service performed, costs classified as direct costs of the product or service would not have come about. *Indirect costs,* like direct costs, are necessarily incurred by a contractor in conducting his business, but, unlike direct costs, they are not easily attributable to any one product or service.

Except general and administrative (G&A) expenses, royalties, the Federal excise tax, and some items included under "other costs," the cost elements on the DD Form 633 can be classified further as either *material costs* or *labor costs*. Total material costs are the costs of the physical matter used directly or indirectly to make an end product. Total labor costs are the costs to the contractor of keeping all workers (direct and indirect) on the job.

By combining what we have said about direct costs and material costs, we can define *direct material costs* as costs of material that becomes part of an end product or special material the contractor must buy to make a specific end product. These costs are obviously traceable to the production of a specific end product and should vary in direct proportion to the number of items produced (that is, if the direct material cost for one item were $10,000, the direct material cost for two items should be $20,000). A typical direct material cost would be a casting especially purchased or fabricated for use in manufacturing an antenna pedestal.

Indirect material costs are not easily attributable to the production of any one end product and generally do not vary in direct proportion to the number of items produced. A sample of indirect material would be a general-purpose oil drawn from stock to lubricate a machine used to bore the casting mentioned above. Listed in figure II-A-2 are typical direct and indirect material items used by Defense contractors.

RAW STOCK
BAR STOCK
SHEET METAL
SHEET COMPOSITION
ROLLED STOCK
ANGLES, CHANNELS

HARDWARE
LOW VALUE (UNDER $50 PER UNIT)
- NUTS, BOLTS, SCREWS
- HINGES
- DRAWER SLIDES

HIGH VALUE (OVER $50 PER UNIT)
- CABINETS
- DOORS
- EXOTIC AND PRECIOUS MATERIAL
- BEARINGS

ELECTRICAL
LOW VALUE (UNDER $50)
- RESISTORS, CAPACITORS
- SIMPLE INTEGRATED CIRCUITS
- WIRE, SLEEVING

HIGH VALUE (OVER $50)
- METERS
- TRANSFORMERS
- MOTORS
- SWITCH BOARDS
- TRAVELING WAVE TUBES
- COMPLEX INTEGRATED CIRCUITS

SPECIALLY SHAPED METAL PARTS
CASTINGS
FORGINGS
EXTRUSIONS

OFFSITE MATERIAL
SPECIAL MOUNTING RACKS
PACKING FOR INTERNAL TRANSPORT
JIGS AND SUPPORT DEVICES

MAJOR SUBCONTRACT
POWER SUPPLIES
ASSEMBLIES

MINOR SUBCONTRACT
GEAR TRAINS
MODULES

REPRODUCTION MATERIAL
STATIONERY
VELLUM
BLUE LINE
AMMONIA
RENTAL OF COPIERS
COMPUTER PAPER AND CARDS

RESEARCH AND TEST MATERIAL
BOTTLED GASES
TEST EQUIPMENT
WIRING HARNESSES

SHIPPING MATERIAL
BOXES
CONTAINERS
CRATES
STENCIL, INK
STYROFOAM

Figure II-A-2. Typical Direct and Indirect Material Items

Direct labor costs are incurred as a direct result of a particular end product's being produced and vary in direct proportion to the number of items produced. *Indirect labor costs* are costs for work done incidental to the manufacture or design of end products but not easily attributable to any one end product. A typical direct labor cost would be the salary paid to a design engineer working on the design of a particular end product. If that design engineer's supervisor spends most of his time supervising engineers working on a particular project, his salary also would be a direct cost. But if the supervisor spends his time developing engineering standards applicable to many products, his salary could be considered an indirect cost (it also could remain classified a direct cost but, as we will discuss later, would be prorated equally to the applicable products). And if his time is spent performing non-product-related duties for the contractor, his salary should be put into the indirect labor category.

Figure II-A-3 shows the breakdown of cost categories just described.

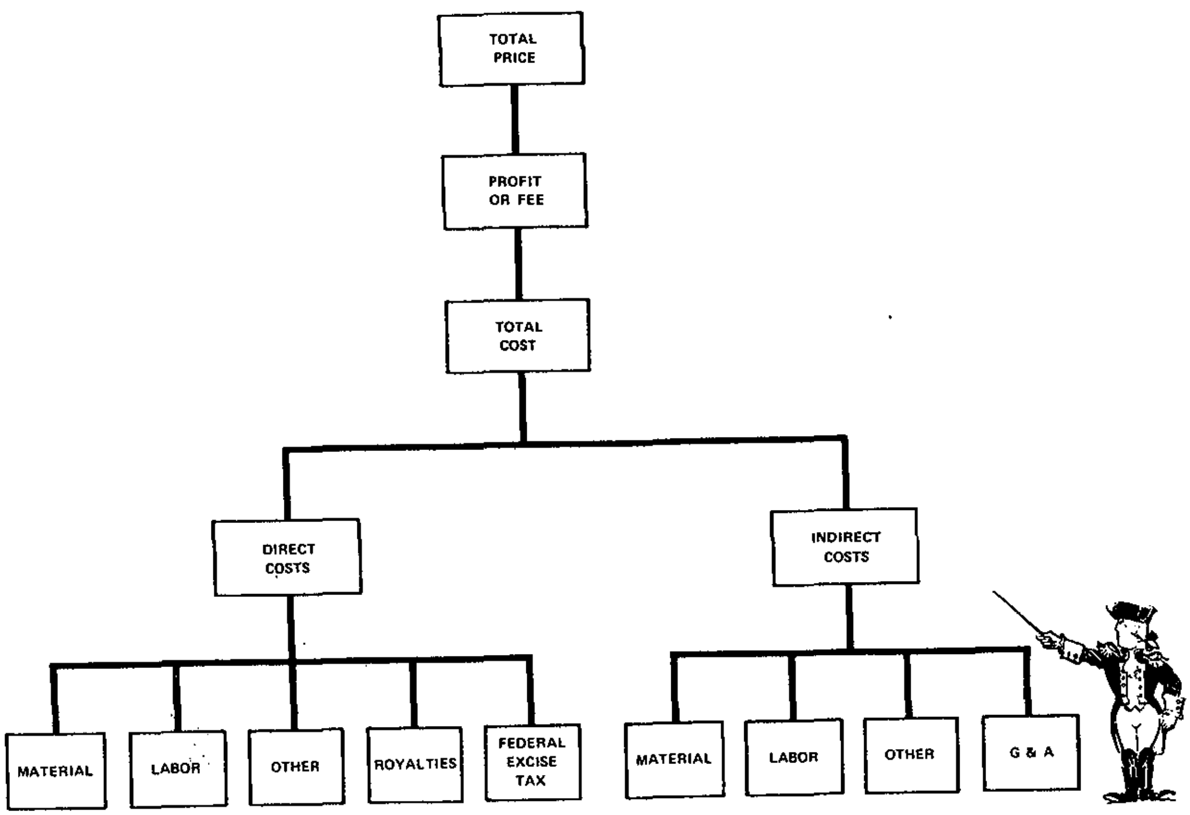

Figure. II-A-3. Cost Categories

COST ELEMENTS ARE BROKEN DOWN IN THE DD FORM 633.

THE DD FORM 633 COST ELEMENTS.

The cost categories shown in figure II-A-3 are not exactly the same as the cost elements on the DD Form 633 (figure II-A-1). A technical evaluator should use the DD Form 633 as a guide to evaluating the different parts of total contract cost, but he also should be familiar with the terms shown in figure II-A-3. Contractors often use these terms.

- *Line item 1.* "Direct material" fits the breakdown on figure II-A-3 without modification; it is "direct material" on both the figure and the DD Form 633. On the DD Form 633, however, direct material is broken down into the subelements of purchased parts, subcontracted items, and "other" material.

- *Line item 1a.* "Purchased parts" are standard commercial items the *prime contractor* (who deals directly with the Government) buys from an outside vendor. These items, charged as direct material costs because they are bought specifically for use in a particular end product, include transistors, switches, relays, and like items.

• *Line item 1b.* "Subcontracted items" are parts, components, or assemblies produced or services performed by an outside vendor (a subcontractor), who for specific reasons can produce the required item or service more economically than the prime contractor can. These direct material items differ from purchased parts in that subcontracted items must conform to specifications developed for the proposed contract and cannot be drawn from preexisting stock. As we discuss later, the prime contractor must be able to show that his decision on whether to make or buy such items has sound basis.

• *Line item 1c.* "Other material" includes the direct material sub-subelements of raw material, standard commercial items, and inter-divisional transfers at other than cost.

• "Raw material" is raw and some processed material items (such as aluminum plates) the prime contractor buys from an outside vendor in such a condition that additional processing will be required.

• "Standard commercial items" are such items as preassembled power supplies, which the prime contractor fabricates and keeps in stock. In many cases, prime contractors list these items in a catalog and sell them to other manufacturers.

• "Interdivisional transfers (at other that cost)" are items sold at selling price by one division or plant to another division or plant under common ownership. The receiving division, which is contracting to the Government, pays cost plus profit to the transferring division, which is acceptable under certain conditions as described later.

• *Line item 2.* "Material overhead," paradoxically, includes indirect labor costs. Forklift operators, stockroom and tool-bin workers, kit preparers, and other employees who handle direct material, except fabrication, assembly and quality control workers, are charged to material overhead. Even warehouse guards are charged to material overhead. In addition, taxes on warehouse property, FICA payments for material handlers, and the cost of telephone service from warehouse to factory usually are included in this cost element.

• *Line item 3.* "Interdivisional transfers at cost" are direct material items differing from interdivisional transfers at other than cost only in that the receiving division pays no profit or fee to the transferring division.

• *Line item 4.* "Direct engineering labor" belongs in the direct labor cost category and includes cost for such efforts as design, reliability and maintainability, quality assurance, manufacturing, and sustaining engineering and the documentation labor required to support those engineering efforts.

• *Line item 5.* "Engineering overhead" includes both indirect labor and indirect material costs, typical of which are engineering supervisors' salaries, social security and taxes applicable to engineers, and engineering supplies.

• *Line item 6.* "Direct manufacturing labor" is the direct labor cost for constructing and testing the end product. Samples of direct manufacturing laborers are listed below, by manufacturing process.

Fabrication	*Assembly*	*Quality control**
Machinists	PB board assemblers	Mechanical testers
Sheet-metal operators	Hand solderers	Continuity testers
Electroplaters	Touchup workers	Environmental testers
Finishers	Wave-solder machine operators	System testers

• *Line item 7.* 'Manufacturing overhead" includes indirect labor and material costs (and other indirect costs, such as the "fixed" costs listed below). Sometimes called manufacturing burden, this cost element includes costs that can be classified as either variable overhead costs (which vary with the number of items produced) or fixed overhead costs (which do not vary proportionately to the number of items produced). Examples of each are listed below.

Variable		*Fixed*
Salaries of:	Overtime premiums	Rent
Supervisory personnel (foremen)	Educational loans	Depreciation
Quality control personnel⁺	Stationary and office supllies	Land taxes
Maintenance personnel	Annual and sick leave	Property insurance
Manufacturing engineers⁺	Group insurance	
Tool-crib attendants	FICA	
Shipping department personnel⁺		
Utility personnel		
Clerical personnel⁺		

*Contractors may classify quality control laborers as either manufacturing workers or engineering workers. We classify them as direct manufacturing laborers.

⁺Costs may be charged as manufacturing overhead costs by some contractors and direct manufacturing labor costs by others; they may even be charged partly to direct cost accounts and partly to overhead accounts by a given contractor. There are no rules against any of this, but as a technical evaluator you should be aware that this does happen so that with DCAA's help you can identify any mistakes that may result in a double charge.

• *Line item 8.* "Other costs" consists of *direct* costs that do not fall logically into any other of the form's direct cost elements. Typical expenses entered here are the costs for special tooling; preservation, packaging, and packing; special test equipment; computer use; and travel.

• *Line item 9.* This subtotal is the sum of all product-related expenses the contractor expects to incur (line items 1 through 8). G&A expenses usually are calculated as a percentage of this subtotal, then added to it.

• *Line item 10.* "General and administrative expenses" are usually called indirect labor costs, but actually they do not relate directly or indirectly to the design or manufacture of end products. Examples of G&A expenses are salaries paid to such workers as personnel officers, bookkeepers, salesmen, advertising experts, and company executives and their supporting workers.

• *Line items 11 and 12.* "Royalties" and "Federal excise taxes" are strictly regulated by Federal laws, compliance with which is monitored by appropriately empowered regulatory and auditing agencies.

THE PLAYERS

THE COST ANALYSIS TEAM

When a technical evaluator sets out to evaluate costs proposed by a Government contractor, he is not alone. He is part of a team of Government cost specialists. He is a key team member, but the work of his fellow team members also is important. Let us look at this team of Government experts.

The *contracting officer* or his representative is the captain of the team. He assembles the team members the Government regularly calls on for cost analysis work and, as he can, recruits whatever other experts whose efforts and advice may help in evaluating cost estimates. Although the *Armed Services Procurement Regulations* (ASPR) and Department of Defense, service, and command directives specify the basic requirements for various organizations' participation in Government procurements,* the contracting officer is charged with obtaining and using to full advantage the available Government talent. He coordinates the activities of his cost analysis team, accumulates data and cost recommendations from all team members, and has final responsibility for evaluating the total quoted contract price. He formally negotiates with the contractor until contract terms are settled or the contract proposed is rejected.

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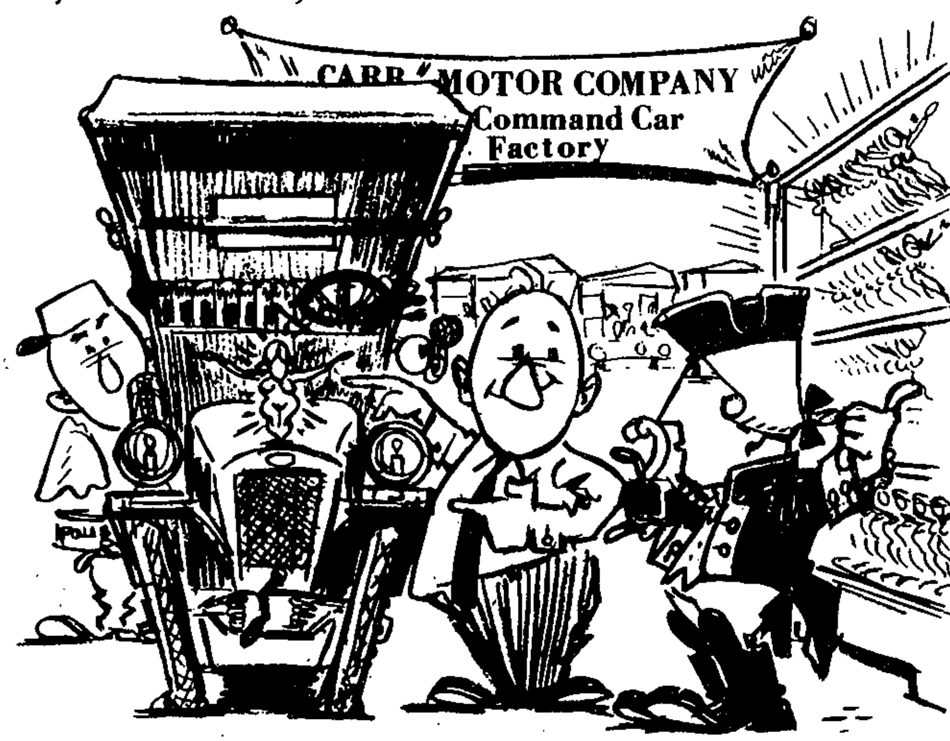
*See ASPR 3-801.3(b) for cost analysis responsibilities.

The Defense Contract Audit Agency (DCAA) regularly audits Defense contractor's cost-accounting methods, including the methods used by major subcontractors to prime Defense contractors. Each DCAA audit covers the accounting methods used for the time period of one whole contract, from pre-contract award to contract completion. After DCAA approves a contractor's accounting methods, they are accepted by the Government until the next DCAA audit, and the contractor must use the methods until then. The contracting officer initiates a DCAA audit whenever he is required by Government regulations or suspects a contractor's accounting methods are improper. Otherwise, DCAA audits are performed at intervals established by Government directives, and for contracts awarded between audits, it ensures only that the contractor is abiding by validated methods. DCAA helps the contracting officer by determining how the contractor has categorized and estimated costs and by validating the material unit costs, hourly labor rates, and overhead and general and administrative (G&A) rates.

Government project office engineers possess training and experience in how to design, test, package, or exercise other specialized engineering skills. They ensure product design and delivery comply with the many Government-invoked specifications and schedules, and identify any "gold-plating" of technical or delivery requirements. ("Gold-plating" means trying to sell services or product features not really needed or desired by the customer.)

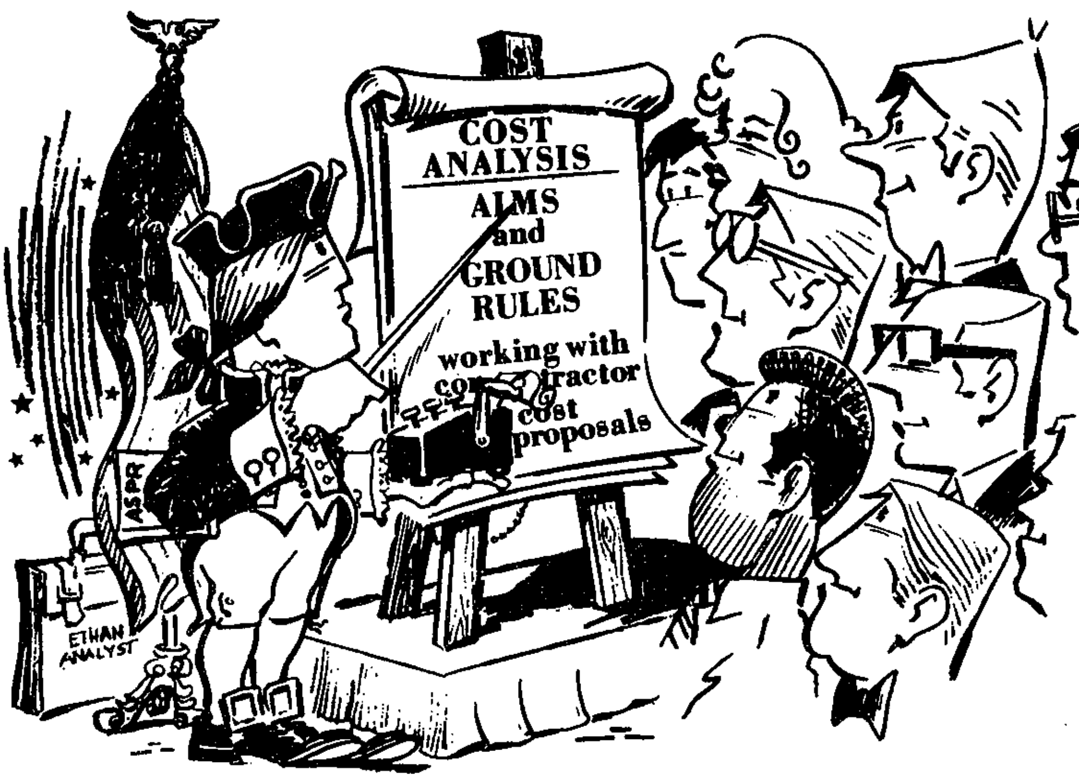


"BUT WE DON'T NEED GOLD-PLATED RADIATOR ORNAMENTS."

Regional or resident plant representatives, such as the Naval Plant Representative Office (NAVPRO), the Air Force Plant Representative Office (AFPRO), and the Defense Contract Administration Services (DCAS), maintain offices in specific geographical areas and, sometimes, in specific plants of major Defense contractors.* These offices provide reviews and services in such areas as production monitoring, inspection, acceptance, safety, labor relations, and administration.

Other government civilian and military experts, such as lawyers and industrial specialists, report to the contracting officer on such areas as interpretations of RFP's and RFQ's the status of appropriations and budgets, and requirements for inserting or waiving particular contract clauses.

Now this seems to be a formidable team--contracting officer, DCAA, project office engineers, resident plant representatives, and such other



"LADIES AND GENTLEMEN . . . THIS WILL BE YOUR 'PRIMARY TOOL' IN COST ANALYSIS."

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*See DoD Instruction 4105.59 of 20 August 1970 (NAVMATINST 4330.29A of 20 October 1970) for additional discussion on the Department of Defense Plant Cognizance Program.

Government experts as lawyers and industrial specialists. Each team member performs a vital function, sometimes including direct cost analysis. So why are technical evaluators needed?

In almost every contract negotiation there is little time between a project office's receipt of a contract proposal and contract settlement, and this is the time allotted to the cost analysis team to evaluate the contractor's proposed costs. As you can see from the above, each team specialist has particular responsibilities, and no team member mentioned so far has a primary responsibility of evaluating all proposed direct costs. On the rare occasions when time permits, some of the above team members may get around to evaluating some of the proposed direct costs. Most often, however, none of these team members has the time to examine, in detail and in the contractor's plant, the bases for the direct cost estimates. Someone is needed to concentrate on these bases.

THE IMPORTANCE OF THE DIRECT COST ANALYST

Not only did we say that the technical evaluator was needed on the Government cost analysis team, we said that he was a key team member. Why? What is it about direct costs that makes direct cost analysis so important?

Direct costs are the nucleus around which total contract price is built. Overhead cost elements usually are calculated as a percentage of some direct cost element, G&A expenses usually as a percentage of direct and overhead costs, and profit or fee as a percentage of the total cost incurred by the contractor.

Figure II-A-4 shows how contractors usually develop total contract price from a nucleus of direct costs. First, material overhead costs are calculated as a percentage of direct material costs. Next, engineering overhead costs are calculated as a percentage of direct engineering labor costs. Then manufacturing overhead costs are calculated as a percentage of direct manufacturing labor costs.

All of these cost elements are added together, and G&A expenses are calculated as a percentage of the direct and overhead costs on the DD Form 633. G&A expenses, along with any royalties and Federal excise tax, are added to the direct and overhead cost elements to derive a total cost estimate. Profit or fee is calculated as a percentage of total cost, then added to it to derive the total contract price. Note in the figure that the direct costs (circled elements) amount to $1060, or 50.5 percent of total cost or 45.9 percent of total price, which is typical.

Now look at figure II-A-5. The direct cost values of figure II-A-4 were reduced by 10 percent, while the overhead, G&A, and profit or fee percentages remain unchanged. The result is a total price reduction of

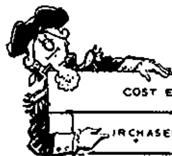
COST ELEMENTS			PROPOSED CONTRACT ESTIMATE		
			TOTAL COST[1]	UNIT COST[2]	REFERENCE[3]
1. DIRECT MATERIAL[4]	a. PURCHASED PARTS[5]		$ 100.00		
	b. SUBCONTRACTED ITEMS[6]		-0-		
	c. OTHER MATERIAL	(1) RAW MATERIAL[7]	200.00		
		(2) STANDARD COMMERCIAL ITEMS[8]	-0-		
		(3) INTERDIVISIONAL TRANSFERS (at other than cost)[9]	-0-		
2. MATERIAL OVERHEAD[10]			15.00		@ 5%
3. INTERDIVISIONAL TRANSFERS AT COST[11]			-0-		
4. DIRECT ENGINEERING LABOR[12]			50.00		
5. ENGINEERING OVERHEAD[10]			50.00		@ 100%
6. DIRECT MANUFACTURING LABOR[12]			700.00		
7. MANUFACTURING OVERHEAD[10]			700.00		@ 100%
8. OTHER COSTS[13]			10.00		
9. *SUBTOTALS*			1,825.00		
10. GENERAL AND ADMINISTRATIVE EXPENSES[10]			273.75		@ 15%
11. ROYALTIES[14]			-0-		
12. FEDERAL EXCISE TAX[15]			-0-		
13. *SUBTOTALS*			2,098.75		
14. PROFIT OR FEE			209.88		@ 10%
15. TOTAL PRICE *(Amount)*			2,308.63		

Figure II-A-4. DD Form 633 with Hypothetical Dollar Values

$230.86 ($2308.63 minus $2077.77). This means that for every dollar saved in direct costs, approximately 2.2 dollars are saved in total price.

In figure II-A-6 we left the direct costs constant and reduced overhead and G&A costs by 10 percent. The result is a $114.20 reduction in the total cost given in figure II-A-4 and a $125.62 decrease in total price. Compare this result with the result of figure II-A-5, when the 10 percent reduction was applied to the direct rather than indirect cost elements. Although total price savings per dollar of direct cost savings depend on the particular percentage factors used for the indirect costs and profit, typically a dollar saved in direct costs yields between two and three dollars saved in total price.

Note that in our examples the percentage of profit or fee was not changed. This was done only to simplify the discussion. Remember that profit and fee interlates with the other elements on the DD Form 633 and must be considered by the contracting officer during negotiations.



COST ELEMENTS	PROPOSED CONTRACT ESTIMATE		
	TOTAL COST[1]	UNIT COST[2]	REFERENCE[3]
1. DIRECT MATERIAL — URCHASED PARTS[5]	$ 90.00		
1. DIRECT MATERIAL — b. SUBCONTRACTED ITEMS[6]	-0-		
1. DIRECT MATERIAL — c. OTHER MATERIAL — (1) RAW MATERIAL[7]	180.00		
1. DIRECT MATERIAL — c. OTHER MATERIAL — (2) STANDARD COMMERCIAL ITEMS[8]	-0-		
1. DIRECT MATERIAL — c. OTHER MATERIAL — (3) INTERDIVISIONAL TRANSFERS *(at other than cost)*[9]	-0-		
2. MATERIAL OVERHEAD[10]	13.50		@ 5%
3. INTERDIVISIONAL TRANSFERS AT COST[11]	-0-		
4. DIRECT ENGINEERING LABOR[12]	45.00		
5. ENGINEERING OVERHEAD[10]	45.00		@ 100%
6. DIRECT MANUFACTURING LABOR[12]	630.00		
7. MANUFACTURING OVERHEAD[10]	630.00		@ 100%
8. OTHER COSTS[13]	9.00		
9. *SUBTOTALS*	1,642.50		
10. GENERAL AND ADMINISTRATIVE EXPENSES[10]	246.38		@ 15%
11. ROYALTIES[14]	-0-		
12. FEDERAL EXCISE TAX[15]	-0-		
13. *SUBTOTALS*	1,888.88		
14. PROFIT OR FEE	188.89		@ 10%
15. TOTAL PRICE *(Amount)*	2,077.77		

Figure II-A-5. Direct Costs from Figure II-A-4 Reduced by 10 Percent

COST ELEMENTS			PROPOSED CONTRACT ESTIMATE		
			TOTAL COST[1]	UNIT COST[2]	REFERENCE[3]
1. DIRECT MATERIAL[4]	a. PURCHASED PARTS[5]		$ 100.00		
	b. SUBCONTRACTED ITEMS[6]		-0-		
	c. OTHER MATERIAL	(1) RAW MATERIAL[7]	200.00		
		(2) STANDARD COMMERCIAL ITEMS[8]	-0-		
		(3) INTERDIVISIONAL TRANSFERS (at other than cost)[9]	-0-		
2. MATERIAL OVERHEAD[10]			13.50		@ 4.5%
3. INTERDIVISIONAL TRANSFERS AT COST[11]			-0-		
4. DIRECT ENGINEERING LABOR[12]			50.00		
5. ENGINEERING OVERHEAD[10]			45.00		@ 90%
6. DIRECT MANUFACTURING LABOR[12]			700.00		
7. MANUFACTURING OVERHEAD[10]			630.00		@ 90%
8. OTHER COSTS[13]			10.00		
9. *SUBTOTALS*			1,748.50		
10. GENERAL AND ADMINISTRATIVE EXPENSES[10]			236.05		@ 13.5%
11. ROYALTIES[14]			-0-		
12. FEDERAL EXCISE TAX[15]			-0-		
13. *SUBTOTALS*			1,984.55		
14. PROFIT OR FEE			198.46		@ 10%
15. TOTAL PRICE *(Amount)*			2,183.01		

Figure II-A-6. Overhead and G&A Costs from Figure II-A-4 Reduced by 10 Percent

Subsection II-B. DIRECT MATERIAL

How much direct material should the contractor charge to the Government?

Other than the end product's design, the most important factor in the contractor's material quantity estimates is his usage practices--how he uses the material. If the technical evaluator finds that the estimates reflect inefficient usage practices, he should recommend that the quantity estimates be reduced.

The technical evaluator, then, is responsible for evaluating the contractor's efficiency in using direct material.

DCAA or a similar auditing agency evaluates prices charged by outside vendors for individual units of material. All direct material, at some time, is bought from outside vendors. Contractors can choose whether to make or buy particular parts, but even for those parts they make themselves they must buy raw material from which to make the parts. (Figure II-B-1 shows the different types of material entering and leaving the plant.)

If DCAA concludes that any material unit price may be overstated, it may "challenge" that price in its audit report. And it challenges the whole unit price, not just the excess. If $100 is quoted for an item, and DCAA finds that it should cost $97, it challenges all 100 dollars, not just the $3 difference.

Are we saying that the technical evaluator deals only with quantities, and DCAA only with prices?

No. The two are inseparable. All unit prices, even those found acceptable in audits, may be challenged by the contracting officer if the technical evaluator finds evidence that those prices may be too high owing to *contractor* inefficiency. DCAA looks mainly at vendor performance, judging it in light of what the vendors were asked to do and current market prices for similar items. Unit prices, however, also are affected by the number of units the contractor buys at one time; as quantities go up, unit prices should come down. In other words, unit prices are affected by the contractor's efficiency in planning his buys.

The technical evaluator, then, is also responsible for evaluating the contractor's efficiency in buying direct material.

The relationship between total direct material cost and the quantity estimates is obvious. Taken together, many units cost more than few units. In evaluating the contractor's quantity estimates, the technical evaluator, at the same time, *is* evaluating the proposed costs.

The technical evaluator makes his recommendations to the contracting officer in terms of costs, not quantities. To do this he must learn DCAA's findings on unit prices, consult with DCAA about his own findings, and with DCAA determine what the unit prices should be. Then he can multiply the recommended unit prices by his recommended quantities to find out how much should be spent on direct material.

BILLS OF MATERIAL

The technical evaluator's most valuable tool for analyzing direct material estimates is the contractor's bills of material (also called parts lists, lists of material, and parts summaries). Most contractors can supply bills for the complete system and all the subsystems, assemblies, and subassemblies.*

What is a bill of materials?

It is a listing and description of the material used in making an end product or particular portion of the end product. For example, in a typical bill of material for an assembly, the items comprising the assembly would be enumerated and the following information about each item would be given:

- Part number
- Part name
- Quantity required per assembly
- Physical characteristics
- Quantity purchased per assembly (when it becomes known)
- Unit price (when it becomes known)
- Total cost (purchased quantity times unit price)

In addition, such miscellaneous information as vendor codes may be given. When purchase quantities and unit prices become known and are entered on the bill, it becomes a "priced bill of material." Figure II-B-2 is a typical priced bill of material for an assembly.

*In descending order, a hardware system can be broken down into the following levels: the complete system, subsystems, assemblies, subassemblies, components, parts, and raw material.

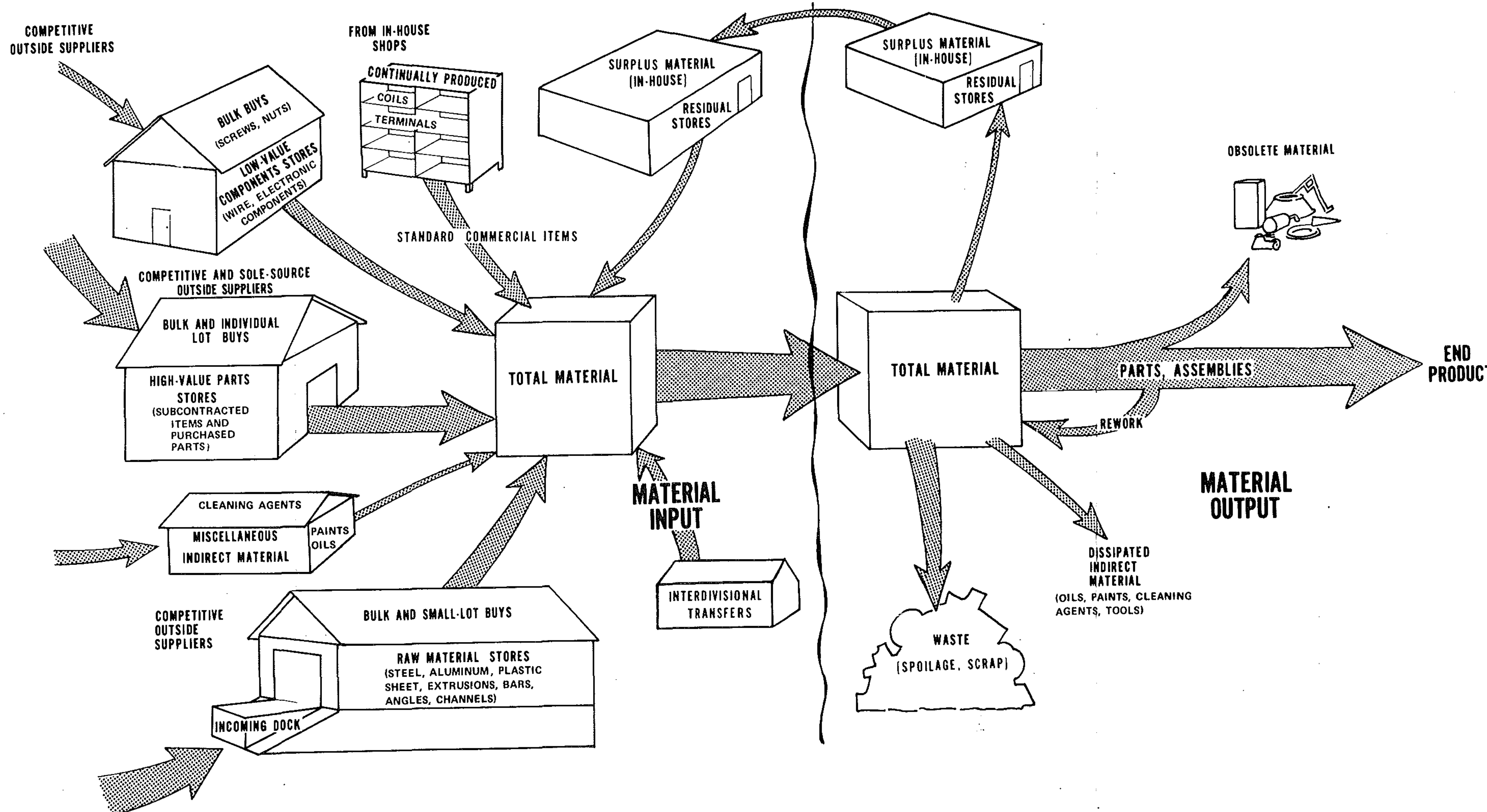


Figure II-B-1. The Flow of the Major Types of Material

Master Parts List for Assembly-Lock 42659

Item	Part No.	Part Name	Required No. per Assembly	Name of Material	Form*	Specification	Quantity Purchased	Unit Cost (in Dollars)	Vendor Code	Total Cost
1	42659	Assembly-Lock	1							
2	65132	Key	2	Steel SAE 1020	Strip	1/8" X 1"	3	1 20	RSC	3 60
3	53265	End-Shackle	1	Steel CRS	Bar	1/4" th	3	1 80	RSC	5 40
4	41920	Front-Shackle	1	Steel 3035E	Bar	1/2" rd	2	10 00	RSC	20 00
5	42411	End-Keyway Assembly	2							
6	33421	Keyway	1	Teflon 1301	Sheet	1/2" sq	3	32 75	UFI	98 25
7	43264	Assembly-Shackle	1	Steel 3035E	Bar	1/2" rd	3	10 00	RSC	30 00
8	52612	Spring-Shackle	4	MIL-S-11316	Plate		630	10	EDS	6 30
9	72653	Assembly Back	2							
10	44321	Spring-Back	2	MIL-S-11310			320	08	EDS	2 56
11	53618	Post-Back	1	Steel 3035E	Bar	1/2" rd	3	10 00	RSC	30 00
12	56234	Back	1	Steel SAE 1020	Strip	1/8" X 2"	3	2 04	RSC	6 12

*All raw stock 144 inches in length unless otherwise specified

Figure II-B-2. Priced Bill of Material for an Assembly

HOW CONTRACTORS ESTIMATE THEIR DIRECT MATERIAL REQUIREMENTS

Contractors estimate their direct material requirements by adding up the material specified in their engineering drawings and specifications. But they also must consider that *the direct material actually used to make the end product always will be greater than the direct material that ends up in the end product.*

SHRINKAGE FACTORS

Have you ever done any woodworking? If you have, you know that the furniture you make is less wood than you bought. Unavoidably, you remove wood when you saw, plane, joint, lathe, drill, and sand. When you make mistakes, you must either rework the bad pieces or throw them away.

Similar operations take place in hardware production, with similar results. For example, if a 12-foot aluminum extrusion were to be cut into 12-inch lengths, only 11, not 12, 12-inch pieces could be obtained no matter how efficient the operator. Assuming the saw blade were as small as one-sixteenth-inch thick, eleven-sixteenths inch of the extrusion would be lost from the blade's passing through 11 times. This would leave eleven 12-inch lengths and one 11-4/16-inch length. The short length, too short for use, would have the same fate as the scrap churned out by the saw blade's teeth.

Now suppose one of the eleven 12-inch lengths were improperly fabricated in a subsequent operation. Such a material loss would be avoidable, because it is due to operator inefficiency. No one can elude mistakes altogether, but they should be minimized and inefficient practices should stop.

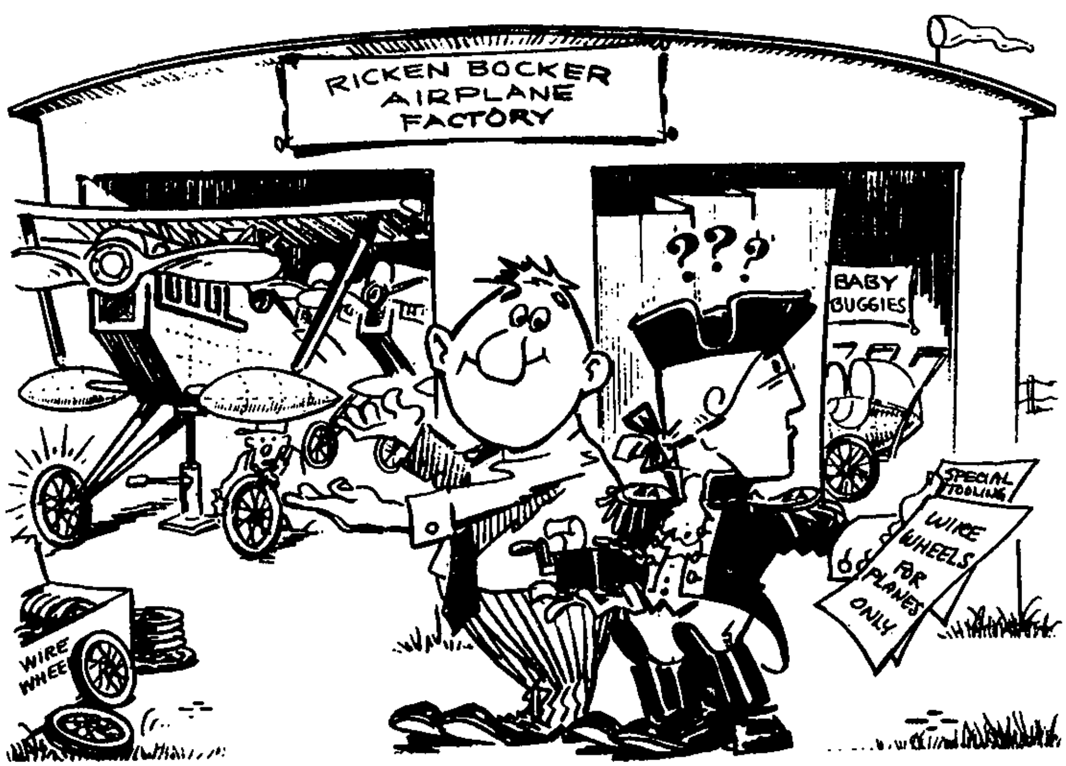
"Overage" is the direct material *not* ending up in the end product. It is bought to account for *"shrinkage"*-- the loss of material during manufacturing operations. To estimate overage, contractors apply percentage factors to the amount of direct material in the end product. These *"shrinkage factors,"* representing the proportion of material consumed to material delivered, are developed from records of past productions of similar items or by measuring consumption in "trial runs," in which a few samples of the end product are produced.

SPOILAGE ALLOWANCES SHOULD BE REASONABLE, SUPPORTABLE, AND BASED ON VALID PRODUCTION RISKS.

To put this into perspective, suppose a contractor's history indicates that for fabricating a particular part he must buy 4 pounds of a raw material for every 3 pounds he delivers. His overage would be 1 pound, or 33-1/3 percent of the 3 pounds in the finished part. His shrinkage rate would be 25 percent, because the lost pound is one-fourth of the 4 pounds bought. To allow for this rate of shrinkage in future fabrications of the part, he would apply a shrinkage factor of 1.33 to the quantity of raw material that will be delivered with the finished parts. (Three times 1.33 is about 4.)

"Scrap" is the direct material that unavoidably does not become part of the end product. *"Spoilage"* is the loss resulting from mechanical or human mistakes in fabrication or assembly. Together, scrap and spoilage are called *"waste."* Some waste can be sold to dealers specializing in reclamation of raw material; other waste is useless and is "junked."

"Surplus material" is the material not consumed because it was not needed. The contractor overestimated material shrinkage and bought more material than needed to fulfill the contract. Surplus material is put into a "residual inventory" for later use, and it should not be charged to the current contract when not used on it.



THE GOVERNMENT WILL NOT PAY FOR MATERIAL THAT WILL BE USED ELSEWHERE.

A change in product design can render material *"obsolete."* As product design becomes less subject to change, fewer instances of material obsolescence should be expected. Highly sophisticated products, such as complex electronic equipment, are highly prone to material obsolescence because of "technological progress." Contractors may quote obsolescence factors apart from other shrinkage factors because, unlike waste, obsolescence is not directly influenced by manufacturing efficiency.

Manufacturing conditions and product characteristics are the two major influences on material shrinkage. The manufacturing conditions that affect material shrinkage are (1) the number of units produced in a production run, (2) the degree of tolerance attainable in the shop, and (3) the degree of automation in the shop. The product characteristics that affect material shrinkage are (1) the physical characteristics of the end product and (2) the value of the material within the end product.

Manufacturing Conditions

Production Quantity. Material unavoidably is wasted each time a machine is set up for a production run because of the "trials and errors" required to get the machine at its proper setting. In a job shop in which parts are produced in lots of from one to 20 units, shrinkage should be between 10 and 50 percent. For every ten parts produced, from one to five parts should be scrapped. In a mass production shop in which parts are produced in production runs of about 1000 units, no more than ten parts should be wasted during the production run--which is a shrinkage of no greater than 1 percent.

Tolerances. Reasonably skilled operators using common machine tools should be able to maintain a tolerance of ±0.020 inch; that is, a reasonably skilled operator using common metal-removal equipment should be able to machine a part to within ±0.020 inch of the dimensions specified for the part. By employing a highly skilled operator or a sophisticated machine, a tolerance within a range narrower than ±0.020 inch, perhaps ±0.0050 inch, could be maintained.

Many part specifications tell how close to the specified dimensions the operator must come. If he fails to perform within this specified tolerance range, the part cannot be used unless it can be reworked. When part specifications state a narrow range of tolerance, the contractor must decide whether to pay for expensive labor and equipment to ensure that tolerance is maintained steadily or to pay for a high overage. He should not pay for both.

Automation. Automation provides more consistency and accuracy than is possible in manually controlled operations. An operator using a numerically controlled drill, for example, should be able to maintain a repeatability of ±0.0001 inch. Each hole he drills should come within ±0.0001 inch of being identical to all the other holes drilled when the drill is operating under one program.

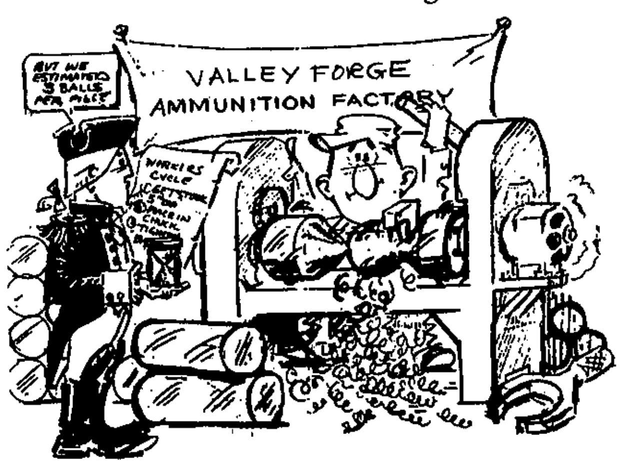
Automation also reduces the craftmanship required of machine operators. A tape-controlled punch press perforates each piece of sheet metal in the same way no matter how inefficient the operator might be during machine-controlled time.

Because automation increases consistency and accuracy and reduces the craftsmanship required to produce end products, shrinkage factors should be lower for automatic operations than for manual operations.

Product Characteristics

Physical Characteristics of the Product. In an electronic assembly you should expect shrinkage for such active, high-reliability components as diodes and transistors to be greater than the shrinkage for such passive components as capacitors and resistors. High-reliability components usually are more fragile than are passive components, and an intricately designed product will be highly subject to design changes. A shrinkage rate of up to 5 percent would be normal for active devices, with a maximum shrinkage of 3 percent the normal for passive devices. For such special items as multilayer boards and encapsulated or protected devices a shrinkage rate of up to 8 percent can be expected.

Value of the Product. When estimating shrinkage, contractors usually give some consideration to the value of the items comprising the end product. For items with high unit costs he probably would allow his workers plenty of time to process the items to minimize the loss of material through worker mistakes. For items with low unit costs he would be less apt to give his workers all the time needed to ensure material shrinkage is as little as possible.



A LARGE SHRINKAGE FACTOR MAY INDICATE MANUFACTURING INEFFICIENCY.

A contractor also should consider the *kind* of labor needed to control material shrinkage. Better qualified manufacturing workers and more product inspectors are required when attempts to control shrinkage are stressed than when controlling shrinkage is less crucial. Keeping these laborers on the job for one hour costs the contractor more than keeping moderately qualified manufacturing workers on the job for an hour. In other words, when a contractor attempts to control shrinkage of a high-cost item, he usually pays more for an hour of labor as well as for more hours. In planning for an acceptable rate of shrinkage, contractors should compare labor costs with material costs to determine whether to accept added labor costs to control shrinkage or to accept the shrinkage to avoid paying added labor costs.

MATERIAL EXPERIENCE CURVES

This method for estimating material costs involves mathematical theories and formulas that we feel are a bit heavy for this narrative. They are described in detail in appendix B.

Although similar in theory to the labor experience curve, the material experience curve has not been as thoroughly documented. The material experience curve's basic premise is that as production quantity increases, the amount of material used per unit of product decreases because of the increase in labor efficiency and the decrease in the number of design changes. It also can be used to account for decreases in direct material unit prices owing to the contractor's scheduling larger production runs as his workers become more efficient. Doing this enables the contractor to buy and store material in larger quantities, which means he can take advantage of more price breaks.

Available historical data indicate that typically the material experience curve follows a 90 percent Wright cumulative average curve (discussed in appendix B).

CONTRACTOR DECISIONS THAT AFFECT MATERIAL UNIT COSTS

The contractor's make-or-buy, lot-size, and multiyear-buy decisions affect how much the Government pays for each unit of material.

MAKE-OR-BUY DECISIONS

Figure II-B-3 shows the reasons for a contractor's making a part or paying an outside vendor to make it.

When an expensive or complex end product is required by a Government contract, the contractor must submit a "make-or-buy program" to the contracting officer. According to ASPR 3-900, "the make-or-buy program is required in all cases except when the

Reasons for making	Reasons for buying
The contractor-- • Can make the parts more economically • Is familiar now with how to make the part • Has greater control over changes • Can avoid paying high freight costs • Designed the part • Can absorb fixed overhead costs	The contractor-- • Can buy the parts more economically • Has limited capital • Has limited manpower • Prefers that the vendor assume the risks • Needs alternate sources of supply

Figure II-B-3. Reasons for Making or Buying

"(1) Bottom line is less than $1,000,000;
"(2) Contract is for research and development;
"(3) Price is competitively based; or
"(4) Work is not complex. . . ."

When a make-or-buy program is required, it should include:

- A list of parts considered by the contractor to be "must-make" items
- A list of parts considered by the contractor to be "must-buy" items
- A list of parts considered by the contractor to be "can-make-or-buy" items
- A statement of his reasons for his make-or-buy recommendations in sufficient detail for evaluation of his technical judgment
- A statement of any "special factors" contributing to his make-or-buy recommendations

According to ASPR 3-900, "special factors" are:

"(1) Contractor's economic justification for performing work that differs significantly from his typical operations,

"(2) Contractor's consideration of other firms as subcontractors, especially small business and labor surplus area concerns;

"(3) Contractor's past make-or-buy history; and

"(4) Other practical elements, such as contractor's capability, market conditions, availability of material and personnel, and future requirements. . . ."

ASPR 3-900 requires contractors to explain any "special factors" because under normal conditions the contracting officer should not agree to a contractor's recommendations for making an item when:

- The item is not regularly made by the contractor and can be supplied by another company, at nearly the same or a lower price, within the quality, quantity, and delivery requirements.
- The item is regularly provided by the contractor but is available with appropriate quality, quantity, and delivery from another company at a price lower than the contractor offers.

When ASPR 3-900 requires a contractor to submit a make-or-buy program, he is not required to explain his recommendations for individual work efforts that cost less than either 1 percent of the total end-product cost or $500,000, whichever is less.

PURCHASE AND PRODUCTION LOT SIZE DECISIONS

Besides his decision to make or buy a part, a contractor must decide how many units he should make or buy at one time to get the most from his money. A "purchase lot" is a quantity of items that a contractor receives and pays for at one time. A "production lot" is a quantity of parts that a contractor makes at one time.

Many vendors vary their unit prices according to how many units are in the lot purchased. Because their "fixed" production costs, such as rent and administrative costs, can be spread over more units in a large buy than in a small buy, they often give "price breaks" to contractors who buy many units at one time. Therefore, to minimize their costs, contractors should buy as many units at one time as they can keep on hand practically.

Because machine setups cause material waste, contractors also should make as many parts at one time as is economically feasible, taking into account schedule constraints. Decreased shrinkage, however, must be balanced against increased storage costs for parts that are finished but not immediately needed. In both production and purchase lots, tradeoffs must be made between savings resulting from price breaks and reduced scrap and expenditures for storage costs and maintaining large inventories. (See appendix C for how to calculate "economical" purchase and production lots.)

MULTIYEAR-BUY DECISIONS

Presently, most Congressional funding is for 1 year only. When it is, the project office receiving funds generally receives only enough to pay the contractor for the fiscal year following the funding.

Hardware production for the Government frequently is more than a 1-year project. In the Department of Defense, projects that will take longer than a year generally are awarded competitively, with funds tentatively committed for up to 5 years. The 5-year ceiling on fund commitments is because the Defense Department has geared project funding to its Five-Year Defense Program. Competitively awarded Defense contracts taking from 1 to 5 years for completion are called "multiyear buys."

When multiyear buys are funded annually, funding beyond the first year--in the "outyears"--can be only tentative when the contract is negotiated. The project office, at the outset of production, can pay only for the first year. And for the outyears, it can state only its intent to carry through with the project and to pay for it. In any outyear, if no money is available, the contractor must cease work on the contract.

Contract cancellation clauses give contractors some protection. By these clauses the Government pledges partial reimbursement to the contractor in the event outyear funding does not come through. Cancellation clauses, however, may or may not allow the contractor to recover *all* of his expenses.

In a multiyear contract, normally only the first year's quantity is funded, and funding for quantities in the outyears depends on subsequent congressional action. In such a case, the Government pays the contractor at the unit cost that would be incurred if all contractually required units were delivered with no production breaks. Then, if work on the contract stops before the contract is completed, the difference between the unit cost at the time work ends and the unit cost paid by the Government is calculated, and the contractor is reimbursed for the difference.

For an example of this, consider a 2-year contract calling for 25 systems. Ten systems are to be delivered the first year and 15 the second. The unit cost for each of the first ten systems is $15,000. With a break in production the unit cost for the final 15 systems is $12,000. With no break in production the unit cost for all 25 systems would be $11,000. In a multiyear buy with options the project office would pay the contractor $11,000 apiece for the first year's ten systems, assuming no break in production because of the stated intent to buy 25 systems. Then, in the second year, if no funds are available and work has to stop, the project office pays the contractor the difference between the unit cost for 25 systems and the unit cost for ten systems. For each of the ten systems delivered, the project office would reimburse the contractor $4000.

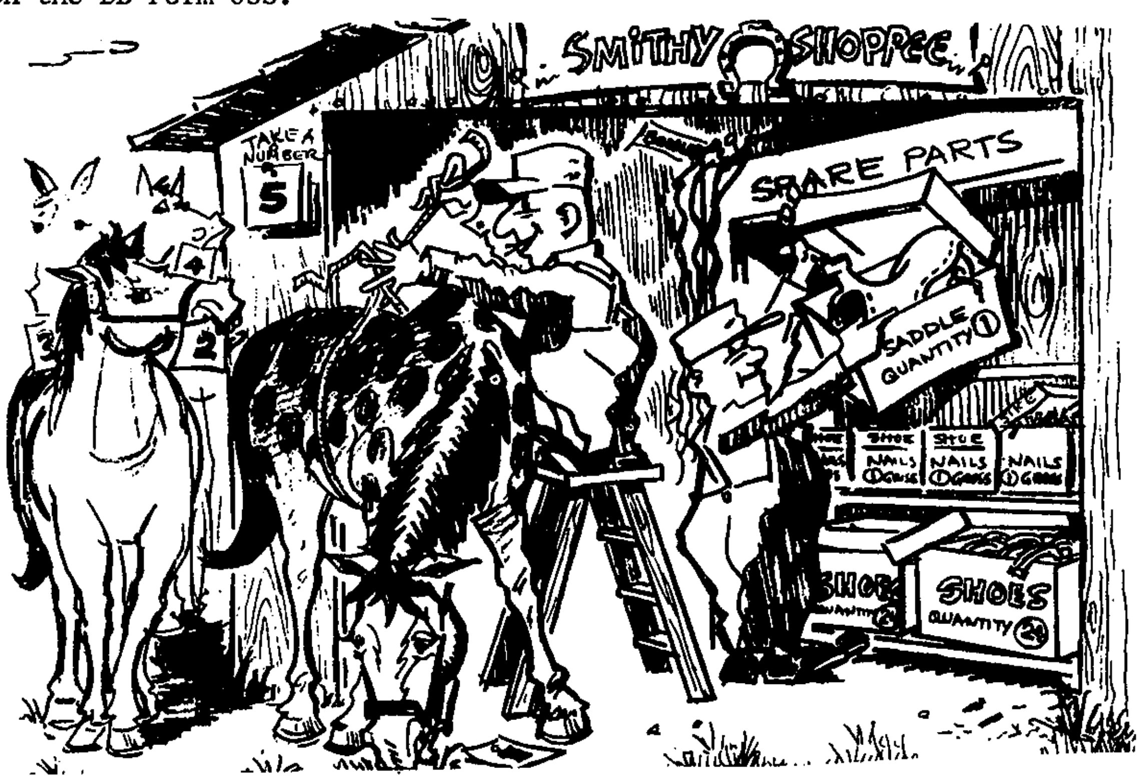
The contractor should plan his multiyear purchases in either of two ways. He can buy the first year's material with firm options for the outyears, which is the procedure just described for the Government's buying from him. Or he can make his purchases without options, but plan them in light of the availability of funds and his delivery requirements.

For an illustration of this second method for planning multiyear buys, imagine a 3-year contract calling for a total production of three radar pedestals. One pedestal is to be produced each year and delivered on November 1, 1972, November 1, 1973, and November 1, 1974. Funding becomes available on October 20, 1971, October 20, 1972, and October 20, 1973. With this arrangement, the contractor could buy material only for the year in which it would be used, allowing no decrease in the cost to the Government for the material used. Thus, if the first pedestal costs $10,000, the second would cost about $10,040, and the third about $10,080. (Inflation has caused an actual rise in material unit costs.)

Now suppose that the delivery dates are October 20, 1972, October 20, 1973, and October 20, 1974, and funding is available June 30, 1971, September 30, 1971, and October 1, 1973. With 2 year's funding available before the first unit is produced, the contractor should buy enough material for the first two pedestals. By taking advantage of price breaks in buying in larger quantity, the total cost for the first two pedestals would be about $19,000, which, added to the $10,080 for the third unit, would give a total cost of $29,080--a savings of almost $1000.

THE DIRECT MATERIAL ELEMENTS

Purchased parts, subcontracted items, raw material, standard commercial items, and interdivisional transfers are the direct material elements on the DD Form 633.



ALTHOUGH SHRINKAGE ALLOWANCES ARE PERMITTED FOR IN-HOUSE PIECE-PARTS, NO FACTOR SHOULD BE APPLIED TO EXPENSIVE SUB-CONTRACTED ITEMS.

PURCHASED PARTS AND SUBCONTRACTED ITEMS

Purchased parts and subcontracted items are items a prime contractor orders from an outside vendor, either because the prime contractor lacks the production capacity to make the item himself, or because the vendor has demonstrated that he can product the item for less, usually because he specializes in producing the particular kind of item. Although the vendor is working under contract arrangement, the prime contractor is liable to the Government for the quality of the subcontracted item. The contractor who has issued subcontracts or purchase orders must be able to supply adequate cost data for cost analysis of the item, *or* he must demonstrate that the item was purchased with adequate price competition.

A contractor should not propose a shrinkage factor for purchased parts or subcontracted items. These items almost always are valuable enough to be guaranteed by the supplier, and he will replace items found to have manufacturing defects at no charge to the prime contractor. When ordering items from outside suppliers, prime contractors should order them in the number actually required for use on the prime contract.

RAW MATERIAL

Of all types of material, raw material shrinks the most. Nevertheless, when contractors buy raw material, which they must do whenever they fabricate parts, they should allow for reasonable shrinkage rates. They also should purchase raw material in economical lot sizes.

STANDARD COMMERCIAL ITEMS

For an item to be classified "standard commercial" it must be used regularly for other than Government purposes and sold or traded as part of normal business operations. The Government does not require cost analysis of standard commercial items required on a Government contract if they are sold at the same price (most favored customer price) in substantial quantities to the general public. Furthermore, the purchase price of a *noncommercial* item may be based on that of a commercial item, provided that the item being purchased is sufficiently similar to the commercial item to permit the difference between prices to be identified and justified without resort to cost analysis.

INTERDIVISIONAL TRANSFERS

Many corporations are highly decentralized. Occasionally in such corporations one division may be able to supply needed parts or material to another division that is contracting to the Government. Because both divisions are in the same corporation, you might assume that the contracting division would charge the Government only the cost for the transferred items, without adding the originating division's profit or fee for supplying the items. After all, the contracting division is charging the Government a fee for producing the end product. To charge the Government another fee for an item going into the end product would seem to be a double-charge on the part of the corporation.

The *Armed Services Procurement Regulations*, however, establishes a Government policy that allows such an originating division to charge a reasonable fee for interdivisional transfers made under either of two conditions: (1) The price (not cost) is an established catalog or market price of commercial items sold in substantial quantities to the general public. (2) The price was favorable under adequate price competition. Under neither condition should the price exceed the transferor's current sales price to his most favored customer. (See ASPR 15-205.55(e) and ASPR 3-807.1(b).)

For any interdivisional transfer, the contracting division should not double-charge overhead and G&A when it uses common accounts with the transferring division. This would occur if the two divisions use the same accounts, the transferring division includes overhead and G&A in its prices, and the contracting division puts those prices on its bills of material without modifying either the prices or the overhead and G&A rates on the DD Form 633. If separate accounts are used, both divisions are entitled to their overhead and G&A costs.

STANDARD AND NONSTANDARD PARTS

"Standard parts" are purchased parts, standard commercial items, or interdivisional transfers for which the Government has written a specification describing their physical design, reliability, function, and other parameters that characterize the part. Ideally, a hardware system could be composed totally of standard parts, but new products demand new parts. On occasion contractors will have need for nonstandard parts to meet new design requirements.

Unlike the performance of standard parts, the performance of nonstandard parts has not been documented. This frequently results in extensive qualification testing of the parts by the contractor, which adds to the system's cost.

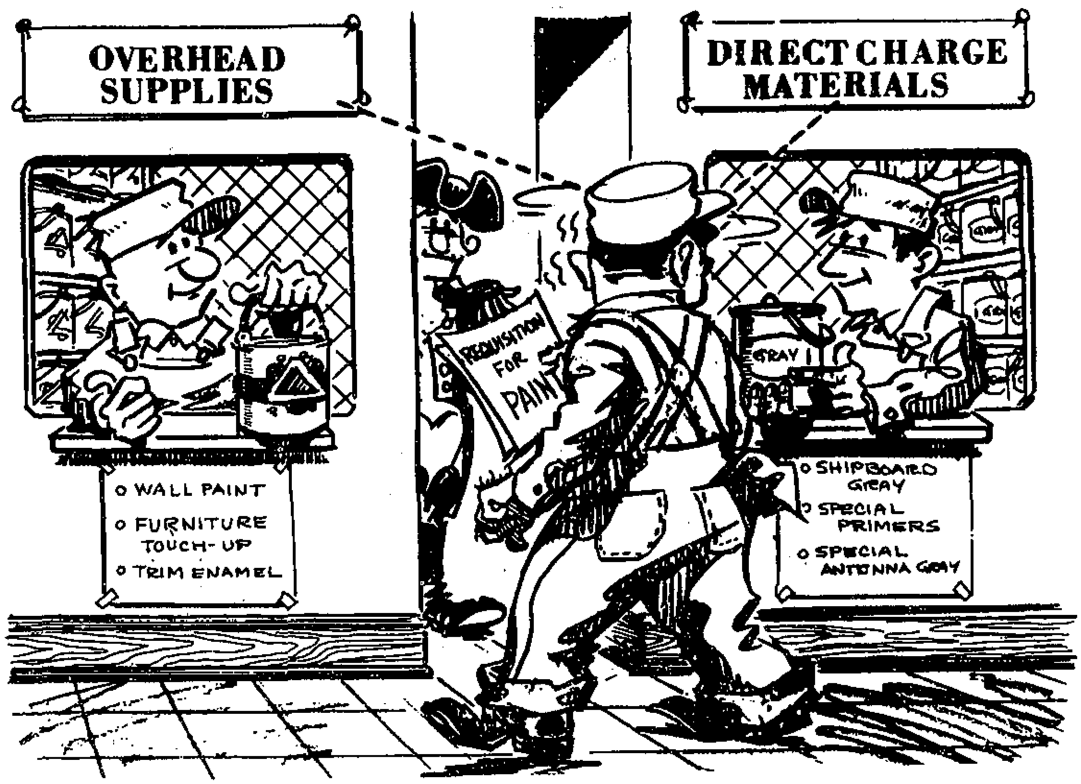
Another disadvantage of nonstandard parts is that neither contractor nor the Government can procure them competitively, which tends to inflate their prices. In short, the Government should discourage widespread use of nonstandard parts.

SPARE PARTS

"Spare parts" is not on the DD Form 633, but the spare parts business is something the technical evaluator should think about when evaluating the direct material elements. Obsolescence in the current contract affects the business of supplying replacement parts once the completed hardware is in field use.

After a contract has been fulfilled and the hardware is in field use, parts eventually wear out and must be replaced. Some parts must be replaced, too, because of obsolescence occurring after the hardware has been installed in the field. This means that someone must continuously manufacture replacement parts. The Government prefers to buy spare parts under competitive conditions, but price competition may not be possible when a part's "complexity" is so great that only the original manufacturer has the manufacturing know-how to make it. And too often the truth is that a part's complexity is increased greatly by repeated changes in design by the original manufacturer.

But if the original manufacturer does win the spare parts business while working on the current-contract, he should buy material for the spare parts at the same time as he buys material for the contract. This would increase the chances for price breaks, which mean lower unit costs.



MATERIAL COSTS SHOULD NOT BE INCLUDED TWICE—ONCE IN OVERHEAD AND AGAIN IN DIRECT MATERIAL.

HOW CONTRACTORS ESTIMATE THEIR INDIRECT MATERIAL COSTS

"What's this? The book's about *direct* cost analysis. Why throw in all this stuff about *indirect* costs? Isn't that someone else's job?"

The technical evaluator primarily is responsible for analyzing direct costs and DCAA is responsible for analyzing indirect costs. The technical evaluator, however, is also responsible for identifying single contractor expenditures that have been charged twice to the Government--once as a direct cost and once as an indirect cost. To identify such double-charges, he should know how indirect costs are estimated.

Indirect material costs may be included either in the plantwide *manufacturing overhead* account or in special proratable accounts maintained by individual departments within the plant.

SPECIAL PRORATABLE ACCOUNTS

Like the plantwide manufacturing overhead account, special proratable accounts are applied as a percentage of direct material cost, direct labor time, or direct labor cost. Unlike the plantwide account, however, special proratable accounts are used to account for indirect material items that are not used throughout the plant and, therefore, are not used for all contracts coming through the plant. The costs of special proratable items (such as epoxy and chemical etching material) are charged by the department using the items, as a percentage of some direct cost category of the particular department, and only to contracts routed through that department in the contractor's plant.

In other words, because of the low unit cost of these items or their lack of "obvious traceability," charging them as direct costs of specific end products is not feasible. And because they are not used in all contracts worked on by the contractor, their costs cannot be incorporated into a plantwide manufacturing overhead rate. They *must* be charged on a departmental basis.

Special-proratable-account rates usually are reviewed and revised more frequently than are plantwide overhead rates (often monthly rather than yearly). Because special proratable items are not used in all contracts and, therefore, their use is less predictable than the use of plantwide overhead materials, contractors normally do not buy them in quantities as large as the quantities in which plantwide overhead items are bought.

PLANTWIDE OVERHEAD RATES

Two methods to account for indirect material used throughout a plant are the "lump-sum" method and the "allocated min-max" method. Both call for the material's cost to be included in the plantwide manufacturing overhead account (DD Form 633 lime item 6).

The Lump-Sum Method

At the close of his accounting period, the contractor using this method adds up all costs recorded for direct and indirect material. Then he calculates the percentage of direct material cost that indirect material cost represents by dividing the total indirect material cost by the total direct material cost. DCAA, in its audit of the contractor's methods, analyzes the contractor's accounting records to see if the total direct and indirect material costs are acceptable and accounted for correctly. If DCAA approves the contractor's indirect material percentage factor, the contractor can apply that percentage factor (as part of manufacturing overhead) to the total direct material cost of each contract he undertakes within the subsequent accounting period.

Suppose a contractor adds up all his direct material costs for his accounting period and finds a total expenditure of $1 million. Over the same time he has spent $56,000 for indirect material. By dividing $56,000 by $1 million, he can find that his indirect material costs have amounted to 5.6 percent of his direct material costs for the past accounting period. If DCAA approves the 5.6 percent, the contractor can use that percentage as a multiplying factor (0.056) for application to the direct material costs proposed for contracts issued in the next accounting period. After that he must calculate a new figure based on historical cost data.

The Allocated Min-Max Method

This method, used mostly by relatively large contractors, is about the same as the previously described method. The exception is that, instead of two categories material is broken down into four major categories: (1) direct mechanical material, (2) direct electrical material, (3) indirect mechanical, and (4) indirect electrical material.

Indirect mechanical material costs are calculated as a percentage of direct mechanical material costs, and indirect electrical material costs as a percentage of direct electrical material costs. Once validated by DCAA, the indirect mechanical material percentage and the indirect electrical material percentage can be applied, respectively, to the direct mechanical material and direct electrical material contract costs estimated by the contractor during the ensuing fiscal year. Depending on whether the contractor specializes in electrical or mechanical work, one of the percentages will be consistently smaller than the other; the larger percentage is the maximum factor applied.

Take again the example of $1 million in direct material costs and $56,000 in indirect material costs. Suppose that the $1 million could be broken down into $600,000 for direct electrical material and $400,000 for direct mechanical material. Right away we can see that probably this contractor's "min" will be mechanical material, and his "max" electrical material. Now suppose that indirect electrical material costs amount to $48,000 and indirect mechanical material costs come to $8000. Forty-eight thousand dollars would be divided by $600,000 to find the percentage of indirect electrical material costs, which would be 8 percent. This 8 percent, when approved, can be allocated to all contracts during the subsequent accounting period as a percentage of direct electrical material costs. Eight thousand dollars would be divided by $400,000 to determine the percentage of indirect mechanical material costs; the answer would be 2 percent, which could be applied to all contracts during the subsequent year. The 0.08 factor, for indirect electrical material costs, would be the "max" allocation; the 0.02 factor, for indirect mechanical material costs, would be the "min" allocation.

We found that by dividing the total indirect material cost by the total direct material cost we would get a factor of 0.056 to be applied to subsequent contracts' direct material costs. But by the min-max allocation method, the min and max factors combined give a total indirect material percentage of 6.8 percent for the 1973 contract cost estimate. This additional 1.2 percent is acceptable, however, because it is based on a ratio of expenses actually incurred by the contractor.

Although this method necessitates more paperwork by the contractor, it usually proves beneficial to him and acceptable to the Government. The Government does insist that min-max allocations be supportable by historical data, and the technical evaluator should examine the data when he suspects double-charging. The min-max breakdown should help the evaluator in locating possible double-charges. (See figure II-B-4 for the examples described for calculating plantwide overhead.)

FISCAL YEAR 1972 DATA

THE "LUMP-SUM" METHOD

$1,056,000 = Total material costs
$1,000,000 = Direct material costs
$ 56,000 = Indirect material costs
56,000/1,000,000 = 5.6% = allocable overhead for all material

THE "MIN-MAX" METHOD USING THE SAME DATA

$1,056,000 = Total material costs
$ 648,000 = Total electrical material costs
$ 600,000 = Direct electrical material costs
$ 48,000 = Indirect electrical material costs
48,000/600,000 = 8% = allocable overhead for electrical material
$ 408,000 = Total mechanical material costs
$ 400,000 = Direct mechanical material costs
$ 8,000 = Indirect mechanical material costs
8,000/400,000 = 2% = allocable overhead for mechanical material
(Because 8 percent is larger than 2 percent, the electrical allocation is the "max" and the mechanical allocation the "min.")

1973 CONTRACT COST ESTIMATES

$5,000,000 = Total material cost
$1,000,000 = Direct material cost
$ 800,000 = Direct electrical material cost
$ 200,000 = Direct mechanical material cost

ALLOCATING THE LUMP-SUM OVERHEAD FROM THE 1972 DATA

$1,000,000 x 0.056 = $56,000 = Total material overhead

ALLOCATING THE MIN-MAX OVERHEAD FROM THE 1972 DATA

$ 800,000 x 0.08 = $64,000 = Electrical material overhead
$ 200,000 x 0.02 = $ 4,000 = Mechanical material overhead
Total overhead under the min-max method = $68,000

(Note: By dividing $68,000 by $1,000,000, we find that the total material overhead by the min-max method is 6.8 percent of the direct material costs. Unlike the lump-sum method's 5.6 percent, this allows the contractor to recover all indirect material costs.)

Figure II-B-4. Calculating Plantwide Overhead

Subsection II-C. DIRECT ENGINEERING LABOR

On line 4 of the DD Form 633 contractors may include not only their engineering costs, but also costs for efforts associated with engineering. Paperwork the engineers turn out must be transformed into legible, coherent documents. Quality control workers conduct tests the engineers develop.* Supervisors assign engineering duties and coordinate the work.

Any or all of these efforts may be charged to direct engineering labor. Indeed, sometimes management costs not directly related to engineering are included in the line 4 figure. Because all of these costs are in support of an end product's production, they are called "technical support costs."

Engineers are busy people. But unlike manufacturing work, it is hard to describe engineering efforts in terms of specific tasks and time requirements before those efforts are under way. Engineers do research, they deal with concepts, and their results seldom are as obvious as the items constructed by manufacturing workers. Also unlike manufacturing efforts, engineering efforts do not regularly consist of operations similar or identical to operations performed many times in the past.

Likewise, document preparation time can be hard to predict, because it depends on the status of the engineers' paperwork--how much they do and when they do it. Management time depends on how long it takes to do the job, so management time--especially engineering management time--is not easily predictable. Quality control time usually can be predicted more readily and accurately than the other technical support requirements, but even when making this estimate the contractor may have to anticipate his engineers' test descriptions.

Despite the difficulties, contractors develop estimates for technical support costs--estimates that must be analyzed.

*Test labor may be included in the direct engineering labor estimate, but usually contractors put it under direct manufacturing labor, which is where we discuss it.

FOUR GENERAL INFLUENCES ON
TECHNICAL SUPPORT COSTS

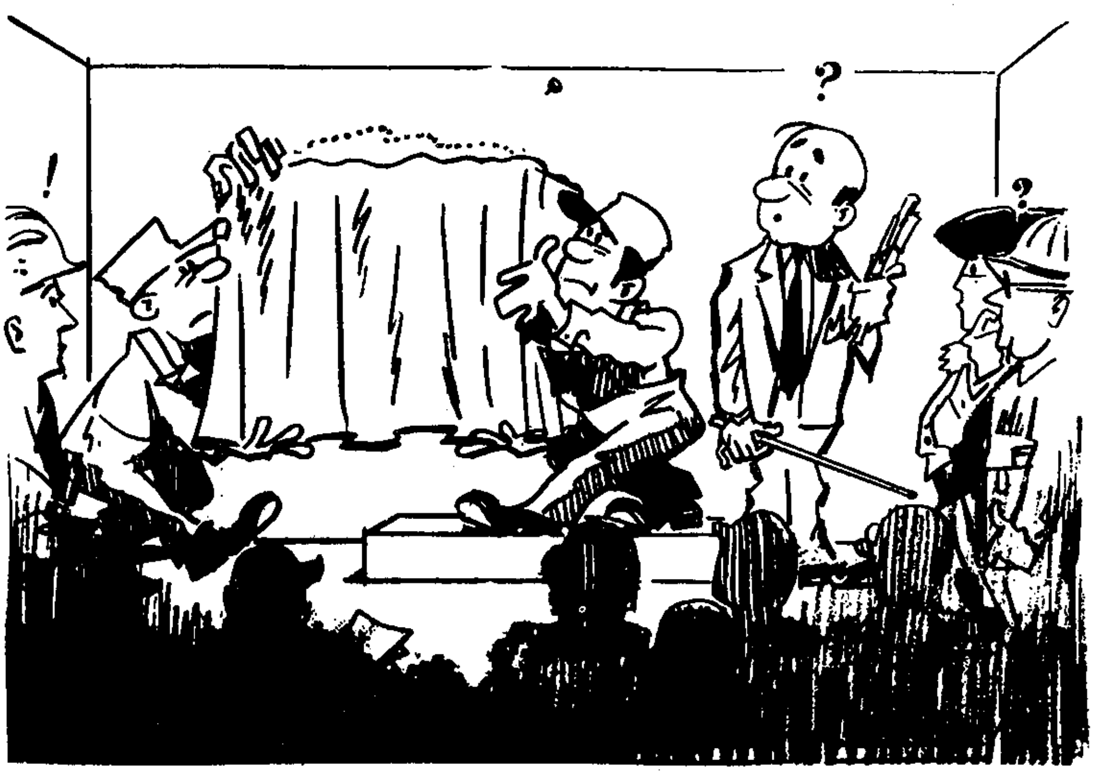
Four general influences on technical support requirements are:

- Product newness
- Product complexity
- The contractor's manufacturing technology
- The contractor's readiness

These influences are interrelated, and any or all can affect a contractor's technical support estimates.

PRODUCT NEWNESS

A product can be "new" in an absolute sense--no one ever has produced it--as is the circumstance of many products produced by the electronics industry. A product also can be new to a particular contractor. Other contractors have made the same or a similar product, but the particular contractor submitting the proposal has never made the sort of product called for. Also to be reckoned with in product newness is the *number of times* the contractor previously has made a similar product.



PRODUCT NEWNESS AFFECTS TECHNICAL SUPPORT COSTS.

The Government does not believe that a contractor without experience in making some product necessarily lacks the ability to make the product. But it does recognize that technical support requirements, especially design and test requirements, generally increase with product newness. In general, a new product will require more of the nonrecurring one-time efforts of initial design development than will a product the contractor is familiar with. Moreover, when product design has not been established in prior contracts, chances are greater for the recurring efforts of design modifications. (In the engineer's vernacular, product design would be "unstable" in such a case.)

Major design changes are priced apart from the original proposal price by procedures called "engineering change proposals" (ECP's), which require separate accounts and payments. But contractors also often make allowances in their original estimates for an anticipated number of design changes, based on prior experience. The Government should not pay for both ECP's and similar design changes anticipated in the basic proposal.

Product newness affects test requirements in that a new product requires more inspection and testing than does a product the contractor's workers have experience with.

A rule to remember about product newness is that *the number of technical support hours required decreases with the increase in design stability*.

PRODUCT COMPLEXITY

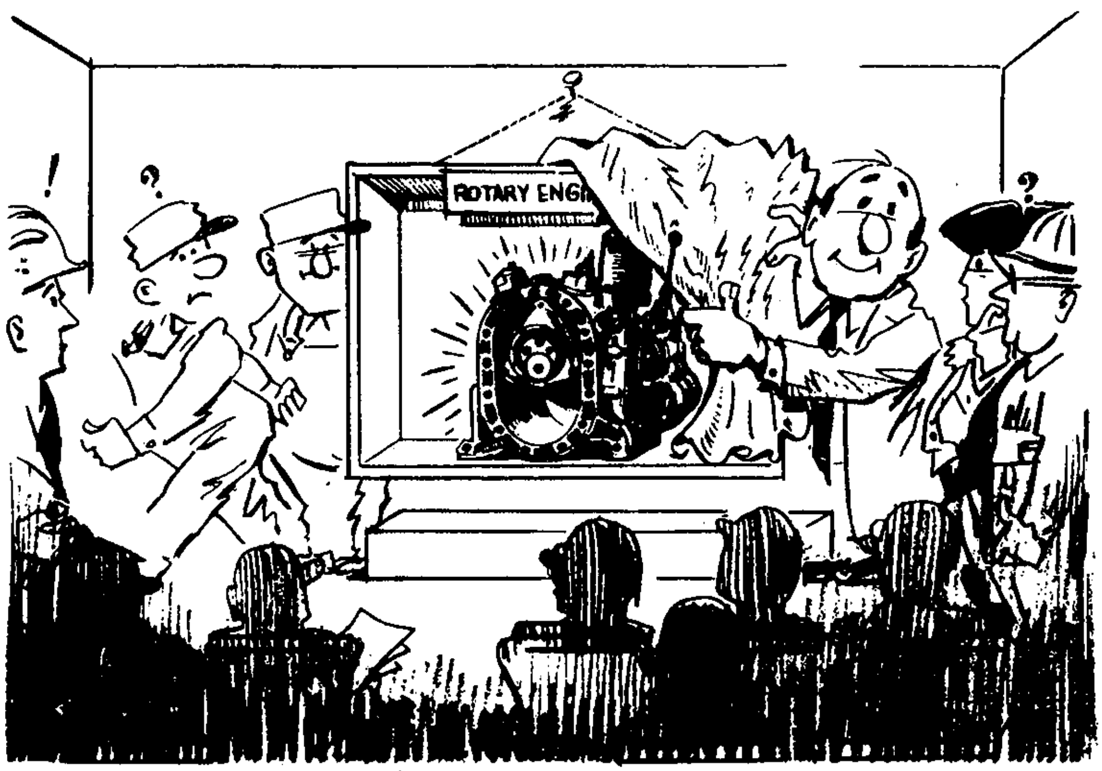
The *Armed Services Procurement Regulation Manual for Contract Pricing (ASPM No. 1)* says the following about product complexity:

> If the contractor is operating at the outer limits of the state of the art, his engineers face the problem of designing equipment which will operate outside known envelopes of performance. New techniques and methods may be required to manufacture the items, and new materials also may be required. Such requirements sometimes drastically increase the engineering man-hours estimates....Yet, while the complexity of the item is quite important, a company's talk about advancing the state of the art...can be misleading. For years, the Government and its defense contractors have pushed forward in research and in the development of new systems and, while items are becoming more complex, the base of knowledge today is far broader than it was years ago....The problems requiring engineering effort...may not be greater now...than they have been in the past and they may be simpler....

As implied by ASPM, a product may appear complicated on paper, but its complexity really depends on how many new concepts it presents to the contractor. Product complexity, then, differs from product newness only in degree. A new product can present one, a few, or any number of new concepts to the contractor; a complex product presents many new concepts.

Sometimes contractors compensate for complexity by simple addition to the technical support estimate. Suppose a contractor's original estimate calls for three quality assurance engineers. On further analysis, the contractor finds several previously unaccounted for design concepts with which all of his quality assurance engineers lack experience. In lieu of experience, then, the contractor can add an additional quality assurance engineer to his estimates to allow for the product's complexity.

Another way contractors compensate for complexity is by a complexity factor. A complexity factor is a multiplying factor applied to increase contract costs by some specific percentage, depending on the product's complexity. A contractor may apply such a factor by multiplying his estimated direct engineering hours by a factor of, say, 1.25. In this case, if 2000 engineering man-hours originally were called for, the complexity factor would increase the estimate to 2500 man-hours. Note that increasing the number of quality assurance engineers from three to four would be the same as applying a 1.33 complexity factor.



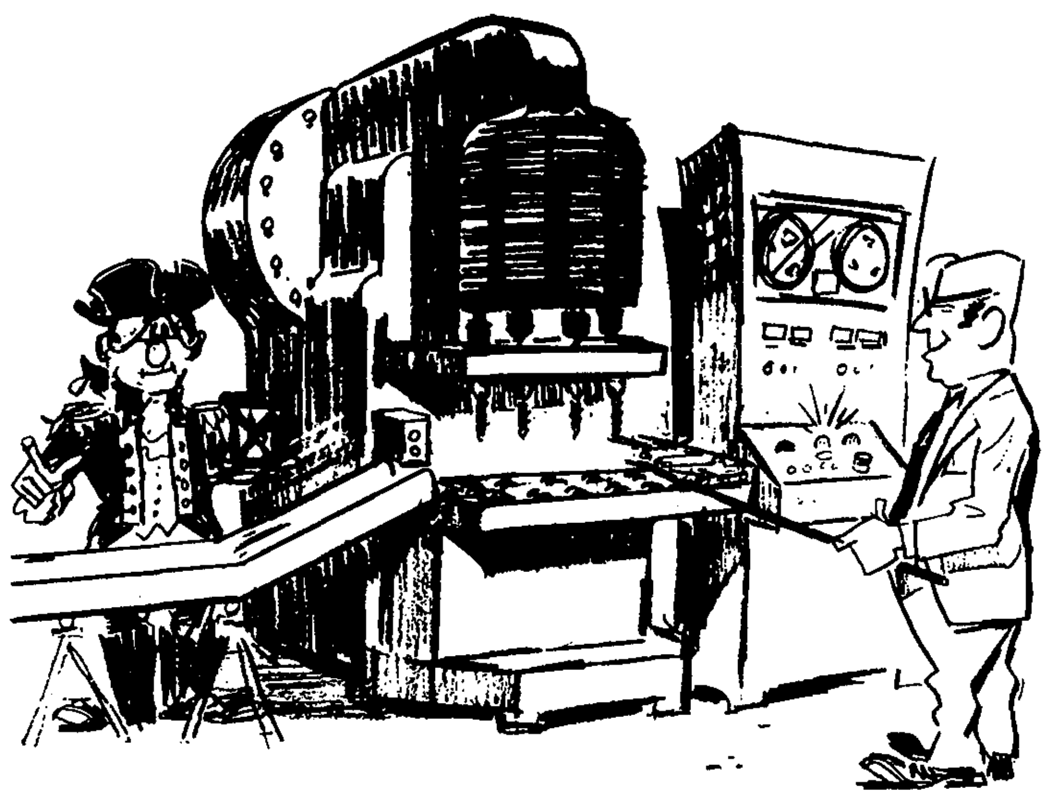
A COMPLEX PRODUCT REPRESENTS MANY NEW CONCEPTS.

Also note that "complexity factor" can be considered a factor applied to labor standards, as discussed in subsections II-D and III-D and appendix A. The complexity factor we have been discussing applies only to technical support hours. *It should not be applied to labor estimates developed from labor standards* because these estimates already should include all time allowances, including allowances for product complexity.

THE CONTRACTOR'S MANUFACTURING TECHNOLOGY

"Manufacturing technology" refers to the degree to which up-to-date machines and methods are used in a plant. It often is related to product newness and complexity in that manufacturing methods may need revision when a contract calls for the production of a new or complex system.

Manufacturing improvements should be judged for their overall net effects. That is, once new equipment has been installed, it may be retained for future use, in which case the contractor's expanded profits will offset his initial outlays.* If the new machines cannot be used on other contracts, the contractor must either discard them or surrender them



COMPLEX NEW PRODUCTS MAY REQUIRE A NEW PRODUCTION TECHNOLOGY.

*When these improvements are new machines, they are considered capital investments and their depreciation costs are charged to overhead.

to the Government. Whether he discards or surrenders them, he must seek to recover his costs as direct costs of the contract for which he installed the necessary equipment.

Increases in manufacturing technology do not entail corresponding increases in the total number of direct hours. True, whenever manufacturing technology is advanced there must be increased engineering labor to program and maintain the new equipment. But subsequent to these technological advances, the number of direct manufacturing labor hours should decrease because of the increased productivity that should ensue. This decrease in manufacturing labor should be greater than the increase in direct engineering labor.

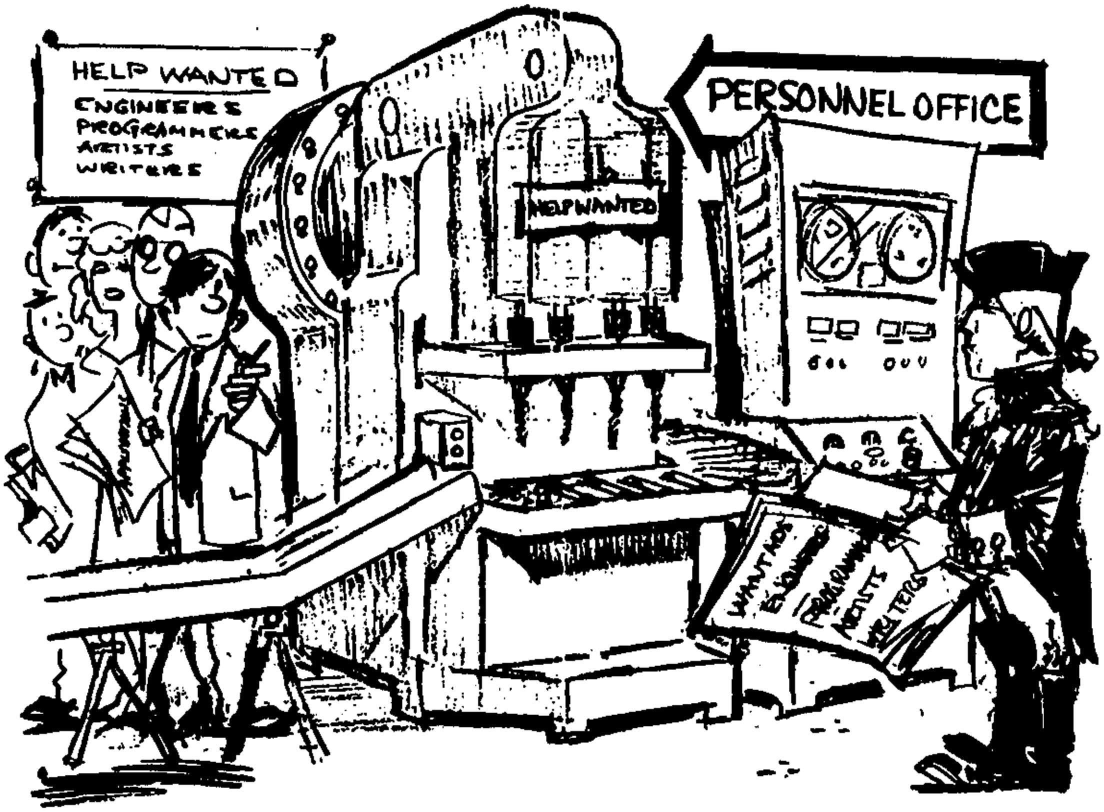
Production conditions affect the amount of technical support required to foster manufacturing improvements. Technical problems faced by a small-lot shop will be greater than those faced by a mass-production shop. Each time the product mix changes, manufacturing engineers have to make the programming changes and other adjustments necessary to maintain the automatic equipment.

Total technical support requirements are affected by whether or not the new processes and equipment have already been installed. If the advanced technology has been in use for some time, the contractor should not charge for the nonrecurring efforts of implementing the innovations.

THE CONTRACTOR'S READINESS

To varying degrees, product newness, product complexity, and the required manufacturing technology can affect the contractor's readiness to begin production. If he is unready, his support costs will be greater than usual.

You can classify the contractor as being in any of three states of readiness: (1) not ready, (2) as ready as circumstances allow, and (3) fully ready. A contractor who is not ready has not completed enough of the support efforts needed before he can begin production. A contractor who is as ready as circumstances allow perhaps faces production of a never-before-produced system, which precludes having prior engineering experience and perhaps the certainty that he has installed the technology that would allow the most efficient production. A contractor who is fully ready has solved all of his technical support problems. (He may never be fully ready, but at least that should be his goal.)



FACILITIES, EQUIPMENT AND MANPOWER ARE PREREQUISITES TO READINESS.

RECURRING AND NONRECURRING EFFORTS

Contractor estimates should be based on data recorded for prior similar work, with requirements for recurring and nonrecurring efforts about the same as the requirements for the proposed contract. All technical support efforts are either recurring or nonrecurring.

A recurring effort is repeated during the contract; a nonrecurring effort is done but once. Because a recurring effort is repeated, if the contractor overestimates his costs for that effort, his overestimate will be multiplied by the number of times the effort is performed. Also, because costs are incurred every time an effort is repeated, contractors should not confuse recurring and nonrecurring efforts. Most nonrecurring efforts occur early in a contract, often before production begins.

ENGINEERING CATEGORIES

By now you know the engineers we are talking about are not train-drivers. But what do they do?

Engineers working on Defense contracts and having college degrees usually have majored in either electrical, mechanical, or industrial engineering. Electrical engineers have studied the properties of electricity and the makeup and operation of electronic apparatus. Mechanical engineers specialize in the overall design and operation of hardware. Industrial engineers are experts in coordinating men, machines, and material to achieve maximum productivity at minimum costs.

Contractors may quote costs for any of these engineering types. But more often they quote costs by the type of work the engineers do on the contract, regardless of their academic backgrounds. These efforts can be broken down into design, manufacturing, quality assurance, reliability and maintainability, and sustaining engineering.

DESIGN ENGINEERING

By the time a contractor begins production, his design engineers will have specified the end product's physical characteristics. The Government requests a product with certain performance capabilities, but often the contractor's design engineers must come up with exact dimensions and material specifications for the product. They cooperate with documentation personnel to produce design specifications, drawings, parts lists, schematics, technical manuals, spares lists, and other documents describing exactly what is to be built (see figure II-C-1).

Design engineering requirements depend mostly on product newness and complexity. If the contractor has produced a similar or identical item before, his engineers should be able to use much or all of the prior work's documentation. Designing a complex end product from scratch takes more effort than designing a simple one, but remember that product newness and product complexity interrelate. Designing a complex item may take less effort than designing a less-complex item if the contractor has previously made items similar to the complex item but not to the less-complex item.

Initially developing a product's design is a nonrecurring effort. Recurring design engineering efforts are modifications to the existing design.

MANUFACTURING ENGINEERING

Manufacturing engineers, sometimes called production planners, plan the direct manufacturing labor activities needed to produce the end product. They are responsible for writing process instructions and methods sheets, for organizing work stations, for assigning tools and machines, and (if they are responsible for production control) for generating and administering schedules to match shop capacity with contractually imposed deadlines.

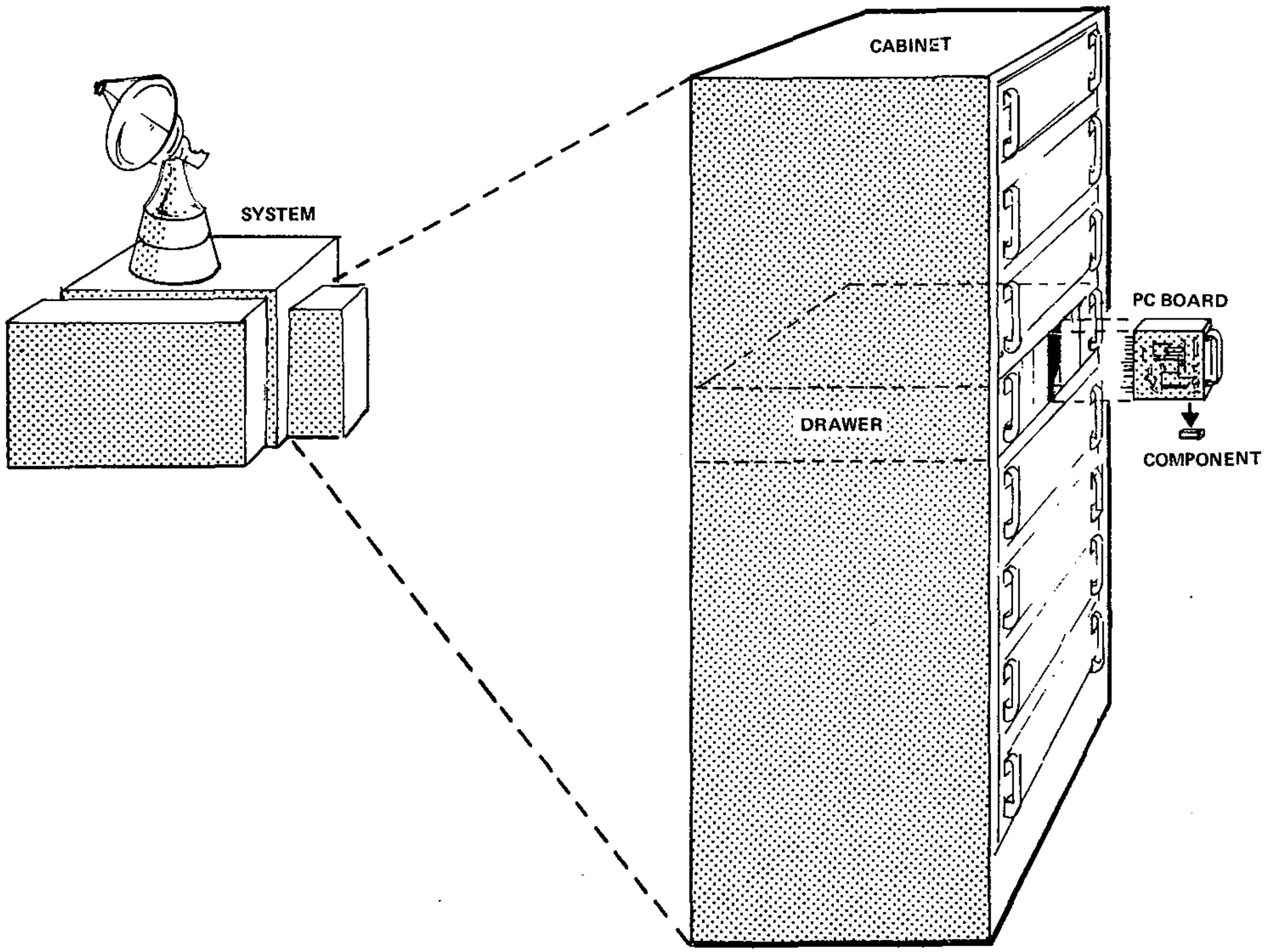
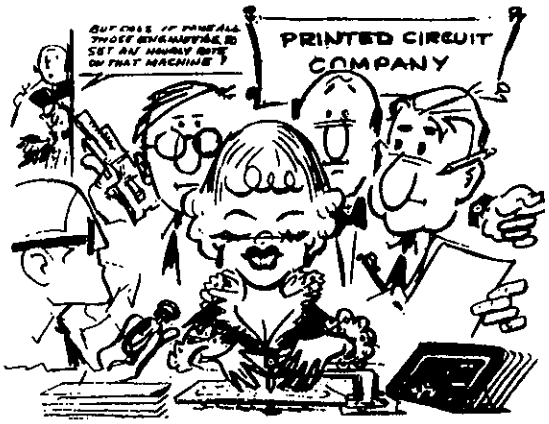


Figure II-C-1. Levels of Design



MANUFACTURING ENGINEERING INVOLVES THE DEVELOPMENT AND IMPLEMENTATION OF EQUIPMENT AND METHODS IMPROVEMENT.

Manufacturing engineers' planning efforts, such as writing procedures, assigning machines, and setting up schedules, generally are nonrecurring. Their administrative efforts, such as reviewing schedules and manufacturing methods, are recurring.

Two basic documents these engineers develop are the visual aid, or work aid, and the process sheet, or manufacturing outline. A visual aid is a coded chart or diagram for shop workers to follow when performing particular assembly operations. (Figure II-C-2 shows a visual aid used in the assembly of electronic components.) Process sheets take more time to prepare than visual aids because fabrication and assembly methods must be described and estimates for individual operations must be developed and entered on the sheets. (An assembly process sheet is illustrated in figure II-C-3.) Visual aids are subordinate to process sheets and depict the assembly operations described in the process sheets.

The number of process sheets required on a particular contract will be directly proportional to the number of parts or modules being produced. In the fabrication area, each part will have its own sketch and process sheets. For assembly operations, one or two sheets are required per module, three to six per subassembly, and seven to ten sheets per full assembly. Each process sheet and associated visual aid will require about 4 hours of manufacturing engineering time, depending on product complexity.

Manufacturing engineering generally requires from 8 to 16 percent of the estimated direct manufacturing labor hours. In the proposal, for every manufacturing engineer called for, there also should be from six to 12 direct manufacturing workers should be proposed.

QUALITY ASSURANCE ENGINEERING

Quality assurance, quality control, or test engineering is the creative effort needed to formulate standards and specifications describing tests and inspections for ensuring that the end product meets the performance criteria expressed in the Government's solicitation. Besides specifying test procedures, quality assurance documents describe the actual design of special fixtures and equipment to be used in

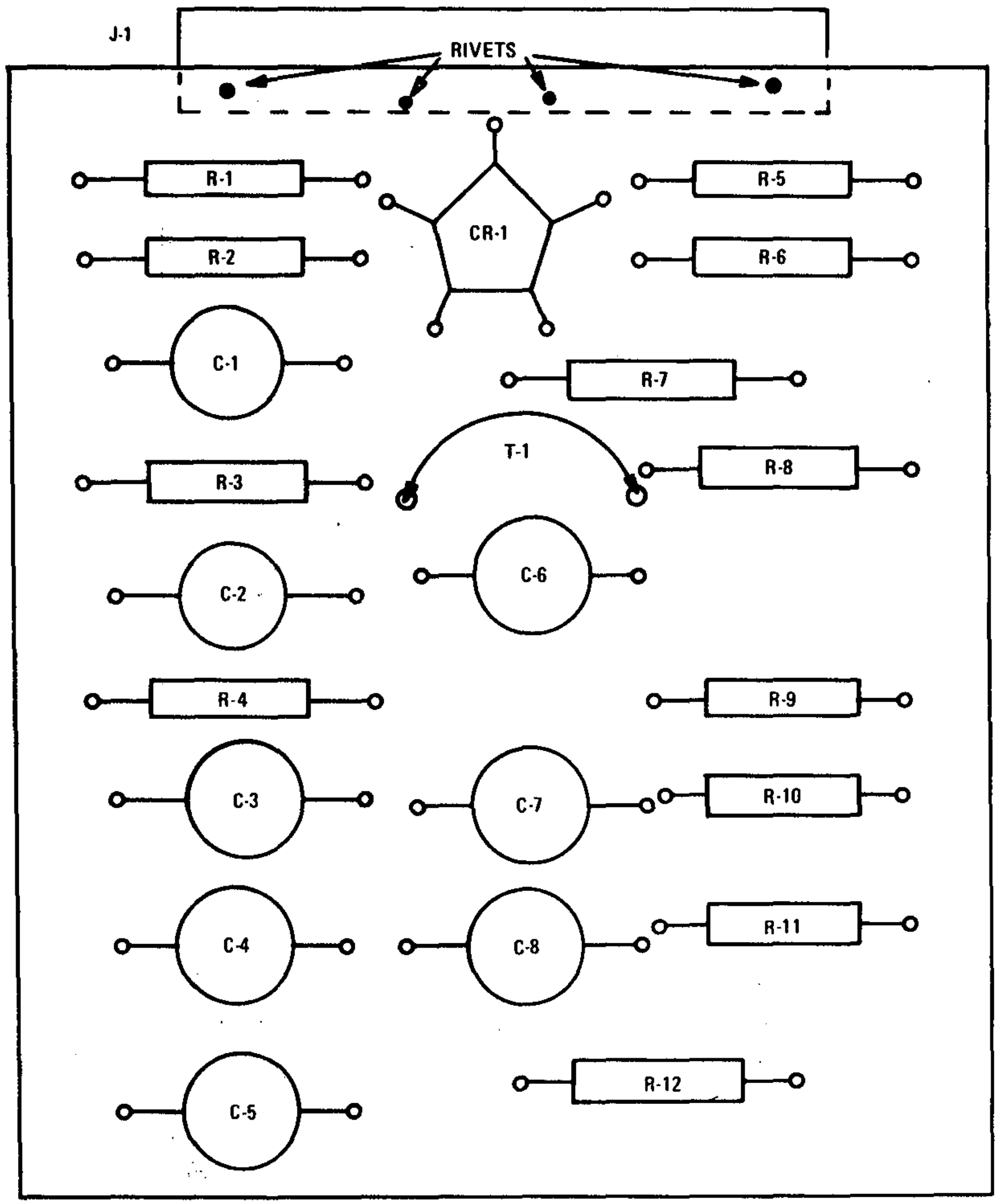


Figure II-C-2. Visual Assembly Aid

ASSEMBLY PROCESS SHEET

Date: 9/1/72
Initial: EAM
Dept: 1622

Part No.: 234567-1
Part Name: Top, Console
Issue: 2

Task: Assemble and solder components to PCB per attached work aid

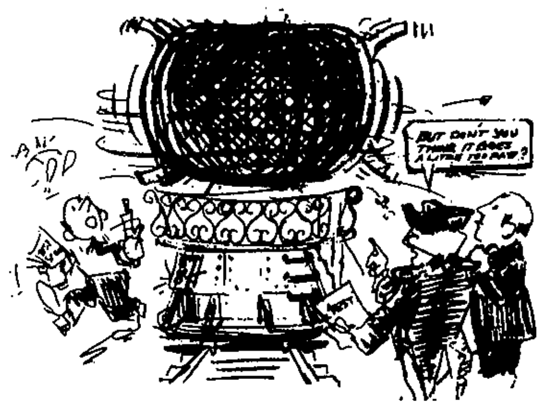
Operation number	Operation description	Std hrs	Qty	Run hrs	Setup hrs
10	Preform 2-lead components	.010	20	.200	.050
20	Preform 5-lead components	.020	1	.020	.050
30	Preform transistor	.015			
40	Preform PC leads (cam type)	.050			
50	Preform jumper	.010	1	.010	.050
60	Assemble 2-lead components	.0078	20	.156	.050
70	Assemble 5-lead components	.015	1	.015	.050
80	Assemble jumper wire	.010	1	.010	.050
90	Hand-solder lead	.005			
100	Flow-solder PCB	.050	1	.050	.050
110	Assemble hardware per nut/bolt	.010			
120	Assemble hardware per nut	.010	4	.040	.050
130	Clean PCB	.100	1	.100	.050
140	Mask per side	.050	4	.200	.050
150	Conformal coat	.050	1	.050	.050
	Total			.851	.550

Leveled run time (.851 hr) x PF&D (1.15) = allowed std run hrs per PCB (.979 hr)

Leveled setup time (.550 hr) x PF&D (1.15) = allowed std setup hrs per lot (.633 hr)

Figure II-C-3. Assembly Process Sheet

conducting the tests. Before the first piece of incoming material can be inspected or the first finished item tested, quality assurance engineers must develop the tests and the designs of the test equipment and quality control workers must install the equipment.



QUALITY ASSURANCE INSPECTIONS ARE INTENDED TO ENSURE DELIVERY OF A SATISFACTORY PRODUCT.

Some degree of quality assurance normally is required at each stage of hardware development, from the fabrication of a small part to the assembly of the complete system. At the completion of each inspection or test, quality assurance engineers analyze the test results, reject substandard material, and make recommendations to the design engineers on whether to continue with or modify the design.

In quality assurance engineering, developing test procedures and designing special test equipment would be nonrecurring. Except in first buy or research and development situations, these efforts should take little time compared with other nonrecurring engineering efforts. The analyses of test results, special testing, and review of ECP's would be recurring.

If the equipment and material used in developing and installing test stations can be used on many contracts, it may be called "capital tooling" and included in engineering or manufacturing overhead. On the other hand, if it is easily traceable to tests of particular products, it may be called "material setup charges" and charged directly to particular contracts as direct material.

Major activities for ensuring an end product meets the Government's needs are shown in figure II-C-4.

RELIABILITY AND MAINTAINABILITY ENGINEERING

Reliability engineers are charged with ensuring that end products are so designed and manufactured as to meet longevity requirements specified by contract. In addition, they are responsible for carrying out a program of documentation and testing to demonstrate compliance with reliability specifications.

Maintainability engineers work to ensure that end products function properly throughout their useful life cycles, taking into consideration the cost-effectiveness of keeping the products in operation. They prepare training and repair requirements, monitor repairs, and perform other efforts to ensure favorable ratios of product use time to product downtime.

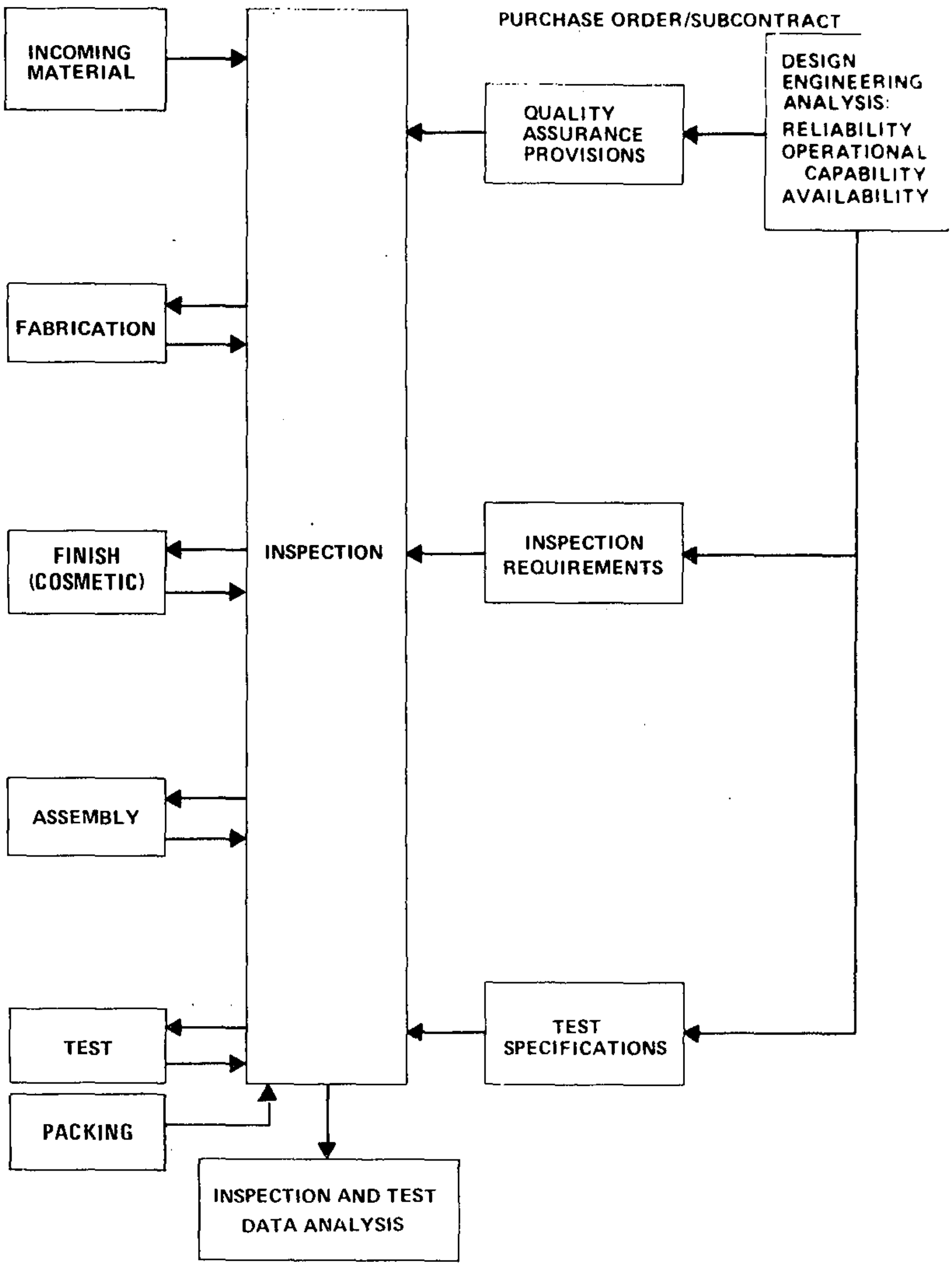
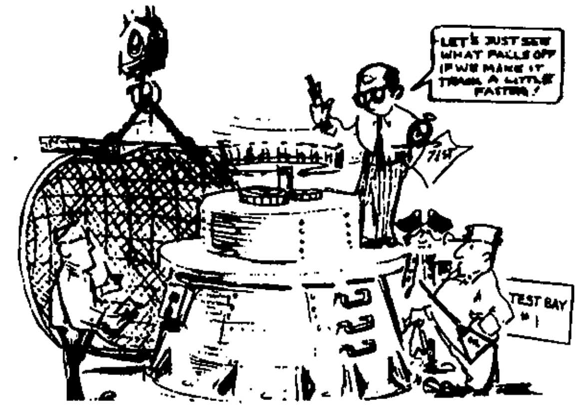


Figure II-C-4. Quality Assurance Activities

Nonrecurring reliability and maintainability engineering efforts include the development of preventive maintenance schedules and written procedures for field tests and equipment maintenance. Recurring efforts include performance of mean-time-between-failures (MTBF) tests and mean-time-to-repair (MTTR) tests and advising the design engineers of the test results.



RELIABILITY ENGINEERING ESTIMATES COVER PROCEDURES AND REPORTS AND TESTING TO VERIFY FAILURE-FRE OPERATION.

The function of design engineers and reliability and maintainability engineers overlap. Reliability and maintainability engineers test the product's design and submit recommendations to the design engineers on how to improve the product. The design engineers consider the recommendations, make design modifications if required, and have the products with the new design tested once more by the reliability and maintainability engineers.

SUSTAINING ENGINEERING

In essence, "sustaining engineering" is a synonym for "recurring engineering." Contractors must assign engineers to watch over production and testing for the lifetime of the contract. These same engineers may have some of their time charged to any of the other categories we have discussed, but the contractor should not charge time for the same effort to both sustaining engineering and some other engineering category.

HOW CONTRACTORS ESTIMATE ENGINEERING LABOR HOURS

Similar to his job of evaluating material unit prices, DCAA evaluates the contractor's charges for an hour's worth of labor, both engineering and manufacturing. But if the technical evaluator sees something he thinks will affect hourly labor rates, he should tell DCAA and the contracting officer about it.

He should keep an eye on the contractor's hiring and firing practices, for new, inexperienced employees usually earn less than veteran workers do. He should look for increased automation, because fewer but better-paid workers come with increased use of sophisticated machinery.

The technical evaluator also should check the proposed labor rates as they relate to contract timing. Owing to cost inflation and worker promotions, labor costs tend to rise over time. The wages the contractor pays at the end of a contract likely will be higher than those he pays at the beginning. The technical evaluator should ensure that the proposed

SUSTAINING ENGINEERS ARE THE "FIREMEN" ON THE PROJECT.

labor rates are at the midpoint of the rates paid during the contract, not the highest rates. The contractor may pay higher wages after the midpoint, but before this he pays lower.

Otherwise, the technical evaluator will be concerned with the proposed numbers of labor hours.

Most contractors develop a separate estimate for each engineering type, then sum up all the estimates. For all of these estimates, however, three methods are commonly used: (1) the work breakdown structure, (2) the level of effort, and (3) the production-to-engineering ratio.

By the *work-breakdown-structure* approach (see MIL-STD-881), the total production effort is broken down into tasks, subtasks, and, finally, "work packages" assigned to individual workers or worker groups. The contractor examines each work package to determine what engineering effort is required to support the production effort described in the work package. This approach also is called the "task" or "work-package" approach.

The *level-of-effort*, or man-loaded, technique presumes that engineers will be needed throughout production. Consequently, a specific quantity of end products produced over a long time span will require more engineering hours than the same quantity produced over a short span. Furthermore, early in hardware development, engineering effort must be keyed to design changes, tooling changes, production disruptions, and schedule changes. This means more engineers are needed then than when stability is achieved. This is illustrated in figure II-C-5.

The *production-to-engineering-ratio* approach, although perhaps not as precise as other techniques, permits quick estimates. It is used mainly for estimating recurring engineering efforts, but on occasion it may be applied to nonrecurring efforts or even the total effort. By this method, the ratio of manufacturing workers to engineers is found for prior work and applied to the proposed contract. The amount of engineering time expended per unit diminishes faster than the amount of production time, but there is a direct relationship between the two. If a contractor's history shows that, for a particular type of work, engineering time has been a certain percentage of production time, he can project his engineering man-hours for the proposed contract once he has estimated his production man-hours. The data substantiating proposed ratios can be found by analyzing either payroll records, labor analysis reports, or industrial engineering surveys.

HOW CONTRACTORS ESTIMATE DOCUMENTATION LABOR HOURS

Deliverable data items are documents the Government project office asks the contractor to prepare and submit and that would not have been prepared otherwise. These documents are not essential to the contractor's engineering or production efforts, and the contractor would not have incurred costs for their preparation had the Government not asked for them. Chapter 18 of ASPM No. 1 describes these costs as being "over and above" the costs of hardware production. After reviewing such a document and its quoted price, the Government can either accept it or reject it.

The Government requires the contractor to price deliverable data items separately from other contract costs. It provides the DD Form 1423, "Contract Data Requirements List" (CDRL), for contractors to list these items and their prices. In filling in the DD Form 633 contractors usually include all costs, including costs of deliverable data items. Should the Government decide not to buy some data item, its price, as stated on the DD Form 1423, should be deducted from the DD Form 633.

The documents the contractor would prepare anyway may be charged to overhead, G&A, or direct engineering labor. All documents charged on

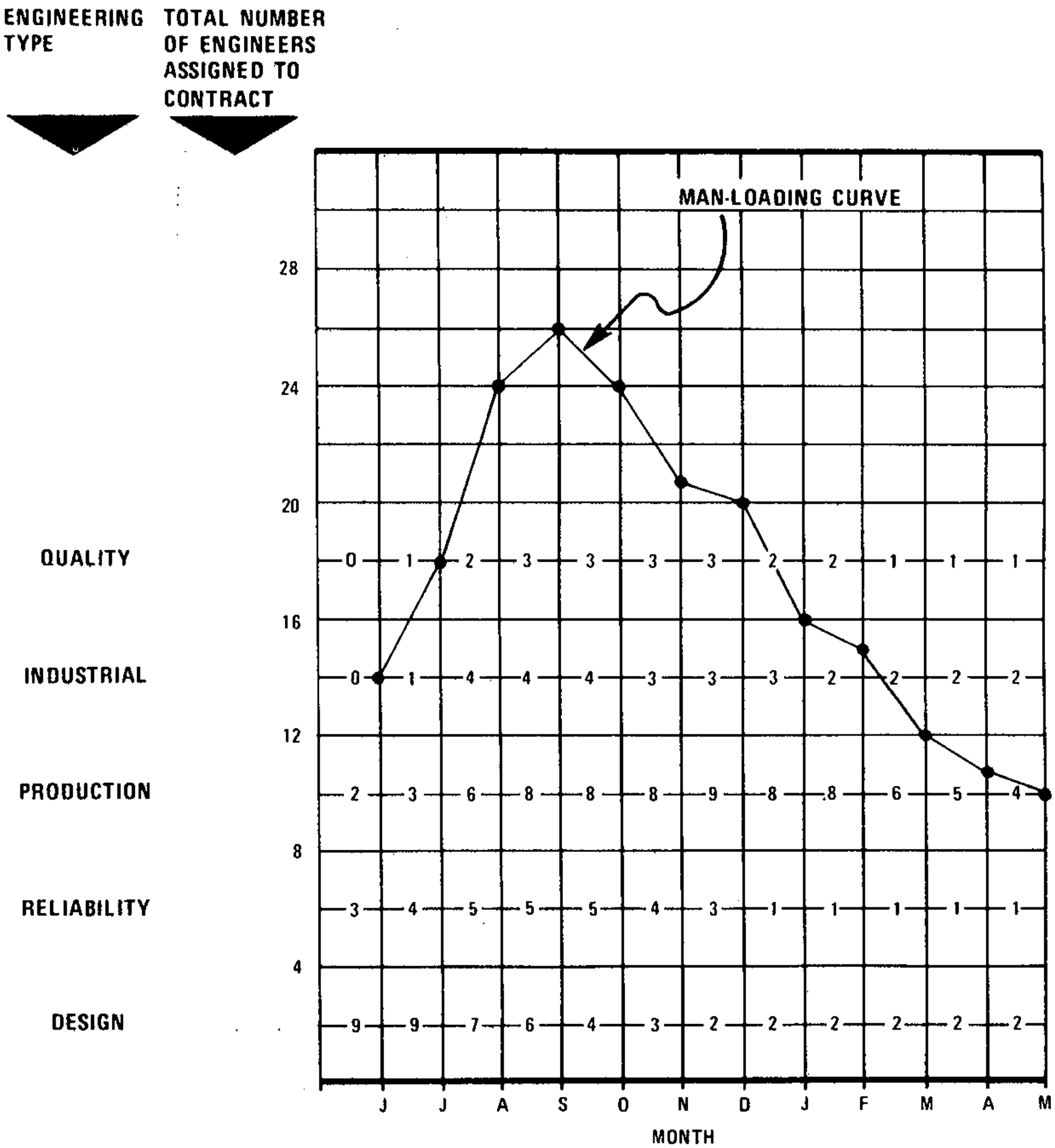


Figure II-C-5. Level-of-Effort Chart

the DD Form 633 must be prepared either because they were essential to production or because the Government requested them.

The following are specific types of documents:

- Engineering documents
  - --Drawings and sketches of assemblies, parts, and tools
  - --Bills of material
  - --Instructions for packaging and handling
- Technical manuals
  - --Users' guides
  - --Installation instructions
  - --Repair manuals
  - --Training handbooks
- Provisioning documents
- Financial and administrative documents
- Other technical documents

The "engineering documents" above are essential to designing and producing any piece of hardware, so their costs are accounted for under direct engineering labor. Technical manuals and provisioning documents, although resulting from engineering efforts, may not be required in the normal course of fulfilling the contract. If they are not, their costs should be listed on a CDRL and their preparation shown to be in response to a Government solicitation. Financial, administrative, and some "other" technical documents may be charged to direct engineering labor. They also may be charged to G&A or overhead, but never should they be charged to more than one DD Form 633 line item.

All documents belong in either of two major classes: textual documents and graphic documents.

TEXTUAL DOCUMENTS

Textual document costs include the costs for the engineering, writing, editing, typing, proofreading, illustrating, reproduction, collation, and binding efforts necessary to produce manuals, specifications, standards, handbooks, reports, instructions, and other written documents. Although these efforts represent quite a variety of salaries and activities, contractors usually quote a lump number of hours to prepare a document page. All of these efforts are considered in the proposed labor cost for 1 hour. Contractors figure total document time by multiplying the hours per page by the estimated number of pages to be published. Then they calculate total document cost by multiplying the total number of hours by their rate for 1 hour of documentation labor.

Whether or not a document is being generated for the first time is the greatest influence on its cost. If production entails new design or other engineering concepts, a document's cost per page will be higher than it would be otherwise. If a similar product has been produced previously, the contractor's engineers and publication specialists may need only to make changes to existing documents. The extent of changes would depend on product differences, and the extent of documentation work would depend on the usefulness of any existing documents, negatives, plates, and so on.

Changes to manuals already in use are charged on a per-page basis according to the average percentage of each page being changed. If more than 70 percent of a page is changed, an entirely new page normally is developed, which takes about 8 hours--4 hours writing, 2 hours liaison, 1 hour editing, and 1 hour typing, copying, and collating. Changes amounting to between 25 and 70 percent of a page will necessitate a revised page, which takes about 4 hours. Changes amounting to no more than 25 percent of a page should call for about 2 hours of documentation time.

The above times apply to instructional manuals addressed to operating personnel. Manuals developed in a research and development environment may take up to twice as long to prepare.

The costs for preparing provisional technical documents, as spare parts lists are called, should be easily traceable. The amount of work required depends on the number of line items in the particular list. Most contractors will require no more than 0.7 hour per line item for preparing a list of less than 250 items, from 0.6 to 0.7 hour per line item for a list of between 250 and 500 items, and no more than 0.6 hour per line item for a list of more than 500 items.

Many of the same labor types required for other textual documents are also needed to prepare provisioning documents. The times given above for provisioning documents include all the required activities, from engineering research and writing through binding and collation.

GRAPHIC DOCUMENTS

In addition to the illustrations placed in technical texts and whose costs are included in per-page costs, contractors generate drawings to show the design of parts on up to and including the complete system. These design breakdowns are charged according to the time spent on them, which is determined by:

- Draftsmen's skill
- Quality of the specifications given to the draftsmen
- Percentage of reworkable drawings
- Complexity of the drawings
- Drawings sizes
- Quantity of each size
- Number of sheets per drawing
- Time required to check out the drawings
- Time required to supervise the draftsmen

Drawing labor costs frequently are based on estimates of hours per square foot of drawing. Hours per drawing will vary from less than 1 hour per square foot for simple repetitive drawings to over 15 hours per square foot for complex designs. For example, a single drawing depicting a servo system with many functions would require better skilled draftsmen for much more time than a simple sheet-metal cutout drawing would require.

The number of hours quoted to prepare a given drawing may or may not include the job of checking drawings and supervision. The time consumed by checkers, who review drafting work for appearance, clarity, and accuracy, may be charged directly to individual drawings. This time normally amounts to about 20 percent of the actual drawing time.

The quantity of each size drawing to be made or modified, if known, is frequently used as a factor for estimating the total drafting costs. A percentage factor based on the number of drawings made or modified from previous similar contracts may also be used.

Table II-C-1 presents a conversion of common drawing sizes from inches to square feet and an approximation of the number of drafting hours that should be consumed. Engineering and checking time is not included in the table. MIL-STD-100 specifies standard sizes for drawings.

HOW CONTRACTORS ESTIMATE MANAGEMENT COSTS

You may find management costs under direct engineering labor, direct manufacturing labor, other direct costs, G&A expenses, engineering overhead, manufacturing overhead, or divided among some of these elements. Top-level management usually is charged to overhead or G&A because its work is unrelated to any one item's production. Management costs that

Table II-C-1. Engineering Drawing Data

Drawing designator	Size In	Size Sq ft	Typical quantity	Standard time	Time per drawing size (hrs)
A	8.5 x 11	2/3	100	2	200
B	11 x 17	1-1/4	30	4	120
C	17 x 22	2-1/2	24	8	192
D	22 x 34	5-1/4	16	16	256
E	34 x 44	10-1/3	10	28	280
F			5	60	300
G			3	84	252
Subtotal			188		1600 (8.5 hrs avg)
Checking time @ 20%					320
Total effort					1920
Average effort per drawing			1920/188 = 10.15 hrs		

can be charged as direct costs are project management costs, line management costs, and clerical costs associated with the direct management costs.

All direct management costs may be charged to direct engineering labor and often are. But line management costs incurred as a direct result of manufacturing activities more often are charged to direct manufacturing labor. Fabrication and assembly shop supervisors and foremen are such line managers. Other line managers, such as engineering, quality control, and documentation supervisors, almost never have their costs charged to anything but direct engineering labor. Contractors who cannot decide where to put a direct management charge may put it under "other costs."

No matter where a contractor accounts for his management costs, if he counts them as direct costs he probably will use the ratio of management time to the people-being-managed time. For a sample of this method, a contractor's historical records may show that for every ten design engineers employed, one design engineer supervisor would be employed. So if a contract calls for 200 design engineers, he could estimate 20 design engineers supervisors, and charge them to direct engineering labor.

Remember, to be considered a direct cost, a management cost must be generated by the needs of a particular contract, be based on reliable historical data, and not be included in any G&A or overhead account.

LEARNING TO THINK TIME

Technical evaluators spend a large portion of their time evaluating the proposed hours for doing a specified amount of work. Labor efficiency is not measured by the salaries of workers, but by the time workers take to do their assigned work. Frequently, direct engineering labor and direct manufacturing labor are the two greatest expenditures on Defense contracts. To ensure the Government pays for a reasonable number of labor hours, technical evaluators must learn to think time.

In measuring labor time, labor can be expressed in units ranging from thousandths of a man-hour to thousands of man-years. Listed below are commonly expressed measurements of working time. We recommend you memorize them.

- 1 man-hour - labor expended by one person during 60 minutes
- 1 man-day - 8 man-hours
- 1 man-week - 5 man-days or 40 man-hours
- 1 man-month - about 160 man-hours or 20 man days*
- 1 man-year - about 12 man-months, 250 man-days, or 2000 man-hours

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*Man-months and man-years are rounded off to expedite estimates.

Most contractors express direct manufacturing labor time (leveled times, standard times, actual times, and bid times) in decimal terms, and technical evaluators must know what they are talking about. If a contractor says an operation requires 0.617 decimal minute, or just 0.617 minute, a technical evaluator should recognize this as 61.7 percent of 1 minute--37 seconds--rather than as some other length of time. Moreover, when running in-shop checks on contractor estimates, the technical evaluator may need to use a decimal timepiece when accurate time measurements are essential.

The formulas for deriving decimal equivalences are:

(1) $\frac{\text{Seconds}}{60}$ = decimal minutes

(2) $\frac{\text{Minutes}}{60}$ = decimal hours

(3) $\frac{\text{Seconds}}{3600}$ = decimal hours

(4) Decimal minutes x 60 = seconds

(5) Decimal hours x 60 = minutes

(6) Decimal hours x 3600 = seconds

Table II-C-2 shows decimal minute and hour equivalences for 1 through 60 seconds. The relationship between seconds and decimal minutes is the same as the relationship between minutes and decimal hours, so the table can be used to convert minutes to decimal hours. Just substitute the heading "minutes" for "seconds" in the first column and the heading "decimal hours" for "decimal minutes" in the second column.

Table II-C-2. Conversion of Seconds into Decimal Minutes and Decimal Hours

Seconds	Decimal minutes	Decimal hours	Seconds	Decimal minutes	Decimal hours
1	0.017	0.00028	31	0.517	0.0086
2	0.033	0.00056	32	0.533	0.0089
3	0.050	0.0008	33	0.550	0.0092
4	0.067	0.0011	34	0.567	0.0094
5	0.083	0.0014	35	0.583	0.0097
6	0.100	0.0017	36	0.600	0.0100
7	0.117	0.0019	37	0.617	0.0103
8	0.133	0.0022	38	0.633	0.0106
9	0.150	0.0025	39	0.650	0.0108
10	0.167	0.0028	40	0.667	0.0111
11	0.183	0.0031	41	0.683	0.0114
12	0.200	0.0033	42	0.700	0.0117
13	0.217	0.0036	43	0.717	0.0119
14	0.233	0.0039	44	0.733	0.0122
15	0.250	0.0042	45	0.750	0.0125
16	0.267	0.0044	46	0.767	0.0128
17	0.283	0.0047	47	0.783	0.0131
18	0.300	0.0050	48	0.800	0.0133
19	0.317	0.0053	49	0.817	0.0136
20	0.333	0.0056	50	0.833	0.0139
21	0.350	0.0058	51	0.850	0.0142
22	0.367	0.0061	52	0.867	0.0144
23	0.383	0.0064	53	0.883	0.0147
24	0.400	0.0067	54	0.900	0.0150
25	0.417	0.0069	55	0.917	0.0153
26	0.433	0.0072	56	0.933	0.0156
27	0.450	0.0075	57	0.950	0.0158
28	0.467	0.0078	58	0.967	0.0161
29	0.483	0.0081	59	0.983	0.0164
30	0.500	0.0083	60	1.000	0.0167

Subsection II-D. DIRECT MANUFACTURING LABOR

A contractor estimates total direct manufacturing labor time by estimating the time required for every direct manufacturing labor process or operation* needed to fulfill the contract. To do this, he relies on either his history or his labor standards, or a combination of the two. His choice of estimating techniques should be based on his system for accumulating cost data--his cost-accounting system.

THE JOB ORDER COST SYSTEM

Under this system cost information is accumulated by individual jobs or orders. This means that whenever the contractor using this system finishes either a complete contract or a production run of a specially made part to be used in a contract, he records his cost data. Mostly the data are historical data, telling only what the contractor actually did. They tell what was produced, how it was produced, in what quantity it was produced, how long and how much money it took to produce it, what material was used, and any other pertinent information.

Most contractors who use this system are job-shop contractors. They do not continuously mass-produce a line of products but make relatively short runs of products according to each customer's specifications. Because of product dissimilarities, the contractor cannot accumulate cost information with the intention of using it to forecast costs for a great number of jobs or orders.

THE PROCESS COST SYSTEM

Under this system, cost information is accumulated at the close of cost-accounting periods (usually each month) rather than at the

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*The total direct manufacturing effort required for manufacturing a system can be broken down into the "processes" of fabrication, assembly, and quality control (if quality control is not considered as an engineering function). These processes, in turn, can be broken down into "operations," such as lathe, welding, and test setup operations.

completion of jobs or orders. Most contractors who use this system either continuously mass-produce a particular end product or continually manufacture a particular *kind* of end product. Either situation demands the continual repetition of identical or highly similar operations. Because work-method changes from job to job or from lot to lot are minimal, the contractor does not need to gather all data necessary to recalculate costs for each new contract or production run. More readily than the job-shop contractor, he can develop and apply labor standards. The data recorded, although telling what the contractor has done, are recorded in a form useful for the development of a labor standards program. They are called "standard-related data."

Standards, though usually based on industrial engineering efforts, may be based on past performances--on a contractor's history--so contractors using standards can and do call at least some of their data "historical data." The major distinction between the data may be that historical data are usually thought of as straightforward, raw accounts of past events and standard-related data have been translated into factors and allowances.

Note that contractors using the job order cost system may develop standards for certain operations or processes, especially ones they perform regularly. Furthermore, for some estimates contractors using the process cost system can decide not to spend money on the industrial engineering efforts needed to develop standards and, instead, base their estimates solely on historical data. (See appendix C.)

USING HISTORICAL DATA AS THE PRIMARY BASIS FOR THE DIRECT MANUFACTURING LABOR ESTIMATE

"Actual time" is a record of the time that actually elapsed when some specific task, operation, or process was performed in the past. If a task, operation, or process performed for a past contract is required for a contract under negotiation, and the contractor has on file a reliable actual time for that task, operation, or process, he can use that actual time as his bid time.

"Bid time" is the time a contractor quotes in his proposal as the time for performing a task, operation, or process. To use an actual time as a bid time, without modification, the actual time must be reasonable, demonstrably accurate, and recorded for work done under conditions nearly identical to those expected for the current effort.

Conditions affecting the use of historical data as the sole basis for determining a bid time are:

- Manufacturing processes physically relocated to another site

• Realignment of production flow within the existing structure

• Changes in type and numbers of equipment

• Changes in overall plant efficiency as shown in current worker output

• A change in position on the experience curve, if used as an estimating tool

When a contractor estimates costs for an item slightly different from some item he has produced in the past, he may apply factors to his cost data to account for production differences. That is, when the contractor is using historical data to estimate costs for an item slightly different from the items made in the past, he can estimate the effects of the difference in terms of time and costs. This estimate is based on his engineers, judgement, and can be called either a "plant condition factor," "manufacturing allowance," or a "complexity factor." (This "complexity factor" should not be confused with the complexity factor frequently applied to engineering labor estimates. See subsections II-C and III-D.)

An experience curve can be plotted from historical data and used to estimate costs. We discuss experience curves later in this subsection.

Figure II-D-1 shows how direct manufacturing labor costs can be determined solely from historical data.

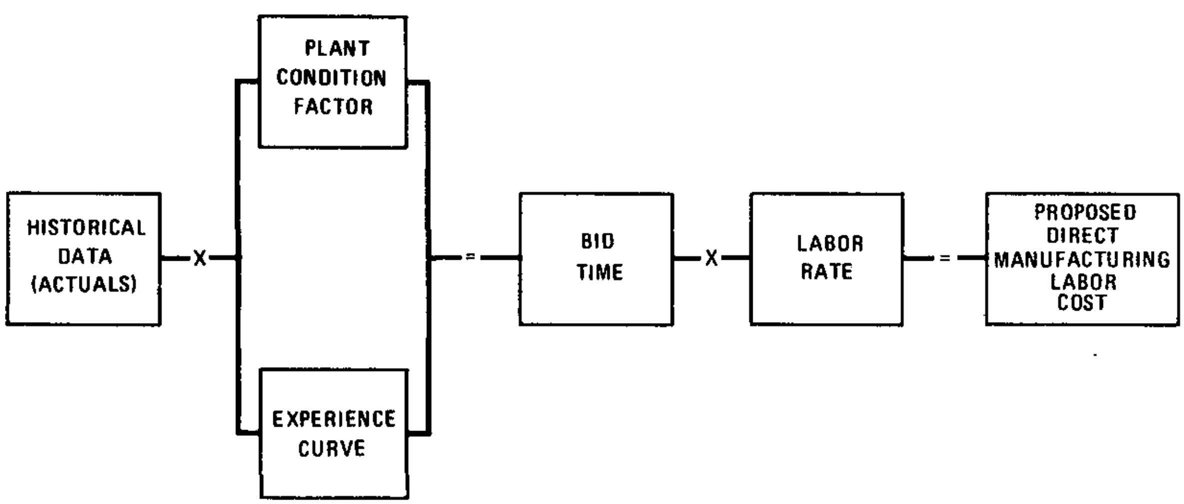


Figure II-D-1. Using Historical Data To Estimate Labor Cost.

USING LABOR STANDARDS AS THE
PRIMARY BASIS FOR THE DIRECT
MANUFACTURING LABOR ESTIMATE

The Defense Department prefers to award contracts to manufacturers with a demonstrated ability to produce a particular kind of product. This means that, although a particular contract may call for a never-before-produced end product, the Defense contractor probably will have experience in making similar products. Many of the required operations will be highly similar or identical to operations performed time and again in the past.

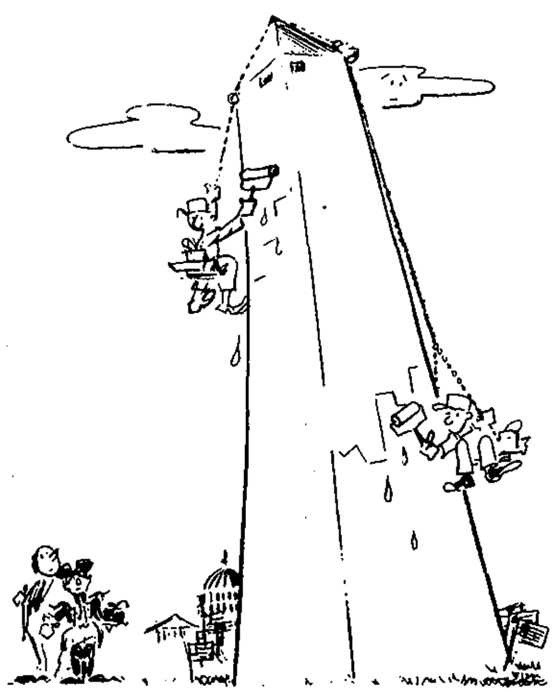
In other words, most Defense contractors use labor standards and maintain a labor standards program. A labor standards program is a file of labor standards the contractor's organization has developed, standard-related data accumulated from within his organization, labor standards developed by other companies, and standard-related data from other sources. (Note: Standards quoted by a contractor are generally his standards and not universally used by industry. Company standards may be considered proprietary information--not for use by other companies.)

A labor standard can be expressed as an *output standard* or as a *time standard.*

- An output standard specifies a production rate for a given product unit produced by a given production method. "Two components (less soldering) mounted per minute" is an *output standard.*

- A time standard is the amount of time to produce one unit or complete one operation. "Thirty seconds to mount one component (less soldering)" is a *time standard.*

"Labor standards," "output standards," "standard outputs," "time standards," and "standard times" are used interchangeably and mean the same thing: the rate of production that an average worker should be able to achieve under normal conditions. But to be more precise, consider the terms as follows:



A FAIR DAY'S PAY FOR A FAIR DAY'S WORK.

• "Labor standards" is the all-encompassing generic term.

• "Output standards" and "time standards" are the terms you use when speaking of labor standards and you need to describe a particular type of standard.

"Standard output" and "standard time" are the terms you use when you need to indicate that an output or time value is a "standard" amount someone should be able to achieve.

In this guide we use the term "standard times." Two definitions of standard time are:

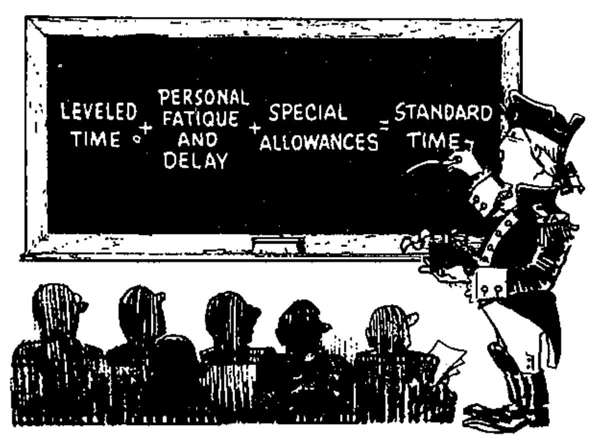
• The time necessary for a qualified workman, working at a pace ordinarily used under capable supervision and experiencing normal fatigue and delays, to do a defined amount of work of specified quality when following the prescribed method.

• Normal or leveled time plus allowance for personal needs, fatigue, and delays.

Standard time is not necessarily the contractor's bid time. Quite often it is not his bid time because standard time usually cannot be achieved until production has been under way for some time. Most bid times, in effect, are standard times plus time allowed for below-standard worker performance owing to inexperience and other reasons. Why sub-standard performance should exist and why such performance should not be counterbalanced by above-standard performance when experience is gained are questions a technical evaluator should ask, but first let us look at standard time.

STANDARD TIMES DEVELOPED IN SHOP

"Standard times developed in shop" are standard times developed for application within a particular department in the contractor's company. Many departments use some standard-related data and standards from other sources, but for now we will assume the contractor is accumulating data within a particular department for use in developing standard times for that department. We are going to develop a standard time from scratch.



The following equation will give you standard time:

Leveled time + PF&D allowance + special allowance = standard time

Leveled Time

Leveled time traditionally has been defined as the working time only that average-skilled worker making an average effort under average conditions normally spends performing a specific operation or process. It does not include special allowances or allowances for personal needs, fatigue, or delays. The three most commonly used techniques for determining the leveled time for an operation are: the time-study technique, the predetermined-leveled-time technique, and the work-sampling technique.

The Time-Study Technique. This technique involves subdividing "work cycles" (operations or tasks) into "elements," which consist of distinct, describable, and measurable fundamental motions. In a turret lathe operation, for example, an element could be "get stud from table and place in chuck," "tighten chuck with socket wrench," or "start machine."

Measuring Performance Time. The elements are listed on a time-study sheet in the sequence in which they are to be performed. The person conducting the study makes one or several continuous observations of the work cycle, during which he makes stopwatch timings of each element and records them on the time-study sheet on which he has listed the elements. Also, he records the skill and effort displayed by the worker, the conditions under which the work is performed, and how much consistency is attained for the kind of work that is being done. Note that when a stopwatch recording is made, the time recorded represents performance time, not leveled time.

IN A TIME STUDY, THE OBSERVER MEASURES AND RECORDS THE TIMES REQUIRED FOR SEVERAL CYCLES OF SOME SPECIFIC WORK ELEMENT.

Figure II-D-2 is a sample time-study sheet with 12 elements listed across the top. The 12 "T" columns represent individual timings of the work cycle's 12 elements. The 12 "R" columns, going from left to right, represent cumulative recordings taken from a stopwatch that ran continuously over the entire work cycle. Under element 1, for example, the first "T" and "R" recordings are 18, or 0.0018 hour (6.48 seconds). Going across the sheet, the "T" recording under element 2 is 19, or 0.0019 hour (6.84 seconds), which was the timing for element 2 taken during that observation. The "R" recording under

STUDY No. 3
SHEET No. 1
OF 1
SHEETS

ELEMENTS		GET STUD FROM TABLE AND PLACE IN CHUCK		TIGHTEN CHUCK WITH SOCKET WRENCH		THREAD STUD		5		STOP MACHINE		REMOVE STUD AND PLACE IN TOTE PAN	
NUMBER		1		2		10				11		12	
NOTES	LINE	T	R	T	R	T	R	T	R	T	R	T	R
	1	18	18	19	37	18	210	10	20	14	34	13	47
	2	21	68	20	88	26	72	10	82	13	95	13	508
	3	20	28	20	48	21	35	11	62 51	16	51 35	15	77 62
	4	25	802	16	18	28	1013	11	24	18	42	12	54
	5	19	73	20	93	19	79	11	90	17	1307	11	18
	6	25	43	19	62	25	42	10	52	14	66	(34)	1600
	7	23	23	(10)	33	28	1812	—	—	—	—	—	—
	8	A 18	2330	15	45	24	28	16	44	18	62	12	74
	9	20	94	20	2614	23	78	11	89	16	2805	13	18
	10	18	36	19	55	32	48	12	60	(22)	82	10	92
	11	18	110	17	27	29	303	12	15	18	33	(08)	41
	12	B 25	430	(43)	73	22	46	14	60	11	71	C 12	792
	13	21	813	14	27	20	1012	12	24	16	40	12	52
	14	28	80	D 19	1137	—	1301	14	15	18	33	11	44
	15												
	16												
	17												
	18												
	19												
	20												
TOTALS "T"		0299		0218		0315				0189		0134	
NO. OBSERVATIONS		14		12		13				12		11	
AVERAGE "T"		00214		00182		00242				00158		00122	
MINIMUM "T"		0018		0014		0018				0011		0010	
MAXIMUM "T"		0028		0020		0032				0018		0015	
RATING (S.E.C. & CY.)		C_1C_1DD											
LEVELING FACTOR		1.11											
L.F. X AVE. "T"		00238		00202		00269				00175		00135	
% ALLOWANCE		15		15		10				15		15	
TIME ALLOWED		00274		00232		00296				00201		00155	

FOREIGN ELEMENTS

SYM	R	T	DESCRIPTION
A	2312 / 1812	500	BREAK STUD
B	405 / 341	64	GET 14 STUDS
C	780 / 671	109	GET DRINK
D	1123 / 1085	38	DROP WRENCH WIPE OFF HANDS
E			
F			
G			
H			
I			
J			
K			
L			
M			
N			
O			

SKILL			EFFORT		
	A1 A2	SUPER		A1 A2	EXCESSIVE
	B1 B2	EXCELLENT		B1 B2	EXCELLENT
✓	C1 C2	GOOD	✓	C1 C2	GOOD
	D	AVERAGE		D	AVERAGE
	E1 E2	FAIR		E1 E2	FAIR
	F1 F2	POOR		F1 F2	POOR

CONDITIONS			CONSISTENCY		
	A	IDEAL		A	PERFECT
	B	EXCELLENT		B	EXCELLENT
	C	GOOD		C	GOOD
✓	D	AVERAGE	✓	D	AVERAGE
	E	FAIR		E	FAIR
	F	POOR		F	POOR

GENERAL RATING FOR STUDY	SKILL	EFFORT	COND.	CONST.
	+.06	+.05	.00	.00

STUDY STARTED	STUDY FINISHED	OVERALL TIME
8:46 A.M. P.M.	9:12 A.M. P.M.	.433 HRS

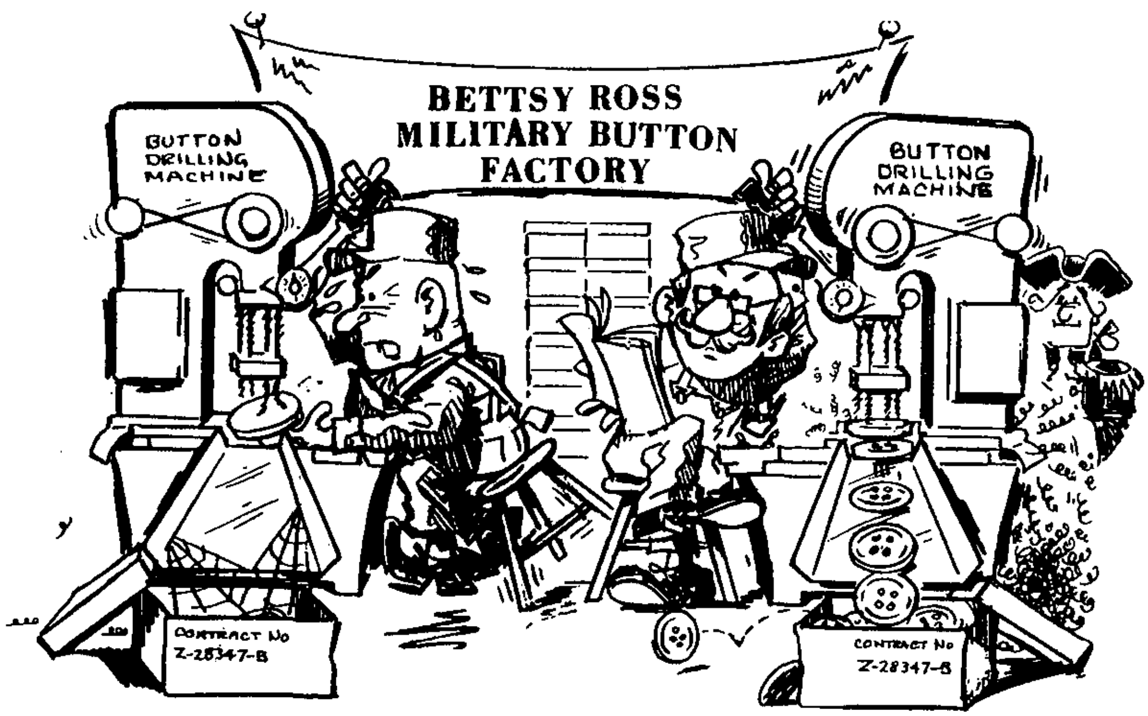
Figure II-D-2. Sample Time-Study Sheet

element 2 reads 37 (0.0037 hour or 13.32 seconds), which represents the time recorded for both elements 1 and 2 from a continuously running stopwatch.

The final "R" recording at the right of the first observation represents the total recorded time for performing the work cycle. Fourteen observations were made of the work cycle, so to find the average performance time either of any element or of the entire work cycle, the time-study man can add the recordings down the appropriate column and divide by 14. Average performance time, however, as you will soon see, does not necessarily represent the leveled time for an element or work cycle.

Leveling. Because worker skill and effort vary, some means must be used to make the timings of worker performance represent the average working time of the average worker working under average working conditions. Without leveling, observed performance time could represent anything from the best performance of the contractor's best worker to the worst performance of a newly hired employee.

Finding a worker with average skill giving average effort under average conditions is unlikely. Even for a worker with average skill and appearing to give average effort, all stopwatch recordings will not



WITHOUT LEVELING, OBSERVED PERFORMANCE TIME COULD REPRESENT ANYTHING FROM THE BEST PERFORMANCE OF THE CONTRACTOR'S BEST WORKER TO THE WORST PERFORMANCE OF A NEWLY HIRED EMPLOYEE.

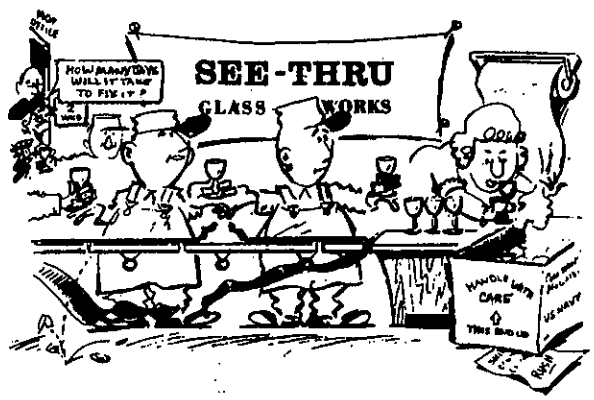
AN EXTREME CONDITION THAT SLOWS THE WORKER'S OUTPUT MAY BE CONSIDERED IN LEVELING HIS MEASURED WORK RATE.

be identical because of minor, often nearly imperceptible differences in motions and effort. But by rating his effort and skill, the conditions of the shop, and the "consistency" attainable in the type of work, you can determine a leveled time for the operation he is performing.

Skill often is rated in the following descending order: (1) super skill (the skill exhibited by a "perfect" worker), (2) excellent skill, (3) good skill, (4) average skill, (5) fair skill, and (6) poor skill.

Effort often is rated in the following descending order: (1) excessive effort (best possible effort from all standpoints but those of health and safety), (2) excellent effort, (3) good effort, (4) average effort, (5) fair effort, and (6) poor effort.

The conditions accounted for by leveling are conditions that affect the operator, not the operation. For example, a machine operator's hands and fingers may be stiffened as a result of the plant being unusually cold on a Monday morning in the winter. This unusual condition will cause the operator to take more time, and the leveling factor can be used in this case to account for the unusual conditions that affect the operator's performance time. But if a broken conveyor belt forced an assembly worker to walk to pick up parts instead of his receiving a continuous flow of parts, the operation not the operator, would be affected by the broken belt, and this condition could not be accounted for the leveling factor.



AN UNUSUAL BREAKDOWN IN THE FACILITIES DIRECTLY IMPACTS THE OPERATOR'S WORK RATE BUT IS NOT TO BE COVERED IN THE LEVELING FACTOR.

Conditions should be rated according to what is average or normal for the place you are evaluating. Because of the extreme heat in a department or plant that is engaged in forging, for example, you may think the working conditions are nearly intolerable. But if those conditions usually prevail in that department or plant, they should be rated average or normal for that particular place.

Conditions, in fact, usually will be rated average.

WHEN PROPER SKILL AND REASONABLE EFFORT ARE USED TOGETHER, THE AVERAGE RESULT IS MORE PRODUCTIVE.

Timings of manual operations will vary more than the timings of automatic operations because human work is more irregular. The kind of manual operation also influences the degree of timing variations. Workers can develop steady rhythms for such elements as picking up moderately sized machine parts. But such an element as picking up circuit components will have irregular timings because sometimes they can be picked up easily and other times they can be extremely elusive.

Highly skilled operators usually are more consistent operators than are unskilled operators and great effort, particularly from operators who are not highly skilled, tends to cause inconsistency.

A large variance in time needed to perform an element usually means that something is wrong with either the operator or the operation. Small inconsistencies can be accounted for by leveling, but the reasons for large variances should be uncovered and corrected.

After skill, effort, conditions, and consistency have been rated, a numerical value can be applied to the ratings. Figure II-D-3 is a performance rating table used by many industrial engineers. Then the numerical ratings can be added to determine the leveling factor for the work performed. The sum of the numerical ratings for skill, effort, conditions, and consistency--the leveling factor--is the percentage above or below average that a particular timing represents.

EXCESSIVE EFFORT WITHOUT COMPARABLE SKILL DOES NOT YIELD AN AVERAGE LEVELED TIME.

Look at the sample time study shown as figure II-D-2. To determine the leveled time for element 1, add the stopwatch timings down column T for all 14 observations of element 1. Your answer should be 0.0299 hour (1.80 minutes). If any stopwatch timing for element 1 has been "abnormal"--either extremely high or extremely low compared with the other timings--it should have been

Skill			Effort		
Description	Letter Grade	Numerical Rating	Description	Letter Grade	Numerical Rating
	A1	+0.15		A1	+0.13
Super Skill	A2	+0.13	Excessive	A2	+0.12
	B1	+0.11		B1	+0.10
Excellent	B2	+0.08	Excellent	B2	+0.08
	C1	+0.06		C1	+0.05
Good	C2	+0.03	Good	C2	+0.02
Average	D	0.00	Average	D	0.00
	E1	-0.05		E1	-0.04
Fair	E2	-0.10	Fair	E2	-0.08
	F1	-0.16		F1	-0.12
Poor	F2	-0.22	Poor	F2	-0.17

Conditions			Consistency		
Description	Letter Grade	Numerical Rating	Description	Letter Grade	Numerical Rating
Ideal	A	+0.06	Perfect	A	+0.04
Excellent	B	+0.04	Excellent	B	+0.03
Good	C	+0.02	Good	C	+0.01
Average	D	0.00	Average	D	0.00
Fair	E	-0.03	Fair	E	-0.02
Poor	F	-0.07	Poor	F	-0.04

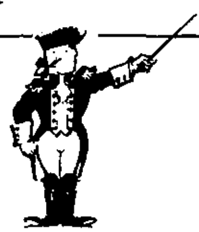


Figure II-D-3. Performance Rating Table

disallowed when computing leveled time. In element 2, for example, two stopwatch timings (0.0010 hour and 0.0043 hour) are abnormal and should not be included when adding the time values in column T.

After you have added the 14 timings for element 1, you must divide the sum of the timings (0.0299 hour) by the number of timings (14) to get the average timing for element 1. Your answer should be 0.00214 hour.

At the bottom right of the time-study sheet is space for rating the skill, effort, conditions, and consistency shown during the time study For the time study in figure II-D-2, skill is rated good, or C1; effort is rated good, or C1; conditions are rated average, or D; and consistency is rated average, or D. Applying the numerical values listed in figure II-D-3, skill is rated +0.06, effort is rated +0.05; conditions are rated 0.00, and consistency is rated 0.00. The leveling factor is found by adding +0.06, +0.05, 0.00 and 0.00 to 1.00. The leveling factor for figure II-D-2 is 1.11.

The leveled time for element 1 is determined by multiplying the average elapsed time of 0.00214 hour by the leveling factor of 1.11. The leveled time for element 1 is 0.00238 hour. That the leveled time of 0.00238 hour is 11 percent greater than the average elapsed time of 0.00214 hour indicates that the workers observed during the time study were performing at a faster pace than that expected of average workers exerting average effort under average conditions and displaying average consistency.

By repeating for the other elements the procedure just described, you can find the leveled times for all elements. Add them together and you have the leveled time for the entire work cycle. A simpler method would be to add the average elapsed timings for all elements and then apply the leveling factor, but this would preclude developing standard data for any particular element.

Description	Time
Reach 8 inches to part	7.9
Grasp part by itself, easily grasped	2.0
Move part to assembly and assemble	8.1
Reposition part during move	---
Release part	2.0
	20.0 TMU's (1.25 seconds)

Figure II-D-4. Sample MTM Data

The Predetermined-Leveled-Time Technique. Predetermined leveled times (often called "predetermined standards") are measurements of the time taken to perform basic body motions, such as reaching for a part or releasing a part. Methods-time measurement (MTM) is an often-used system for developing predetermined times, a sampling of which is shown as figure II-D-4. There are other commonly used systems besides MTM. A few contractors develop their own systems.

With the MTM system, leveled times are measured in time-measurement units (TMU's). A TMU equals 0.00001735 hour or one-sixteenth of a second, its origin being the length of time to shoot one motion-picture frame using a 16-millimeter camera when photographing body motions.

Whatever the source of the predetermined leveled times, the contractor can use them to develop his internal standard times. By adding together the predetermined leveled times for the body motions required to perform an operation, the contractor can determine the total leveled time for performing the complete operation. Note that each predetermined leveled time is leveled, so no further leveling should be required. Predetermined standards for innumerable body motions made under various conditions are available in industry publications (see the bibliography).

If predetermined leveled times are used properly, standards should be more accurate than they would be if some other technique were used. Development of predetermined leveled times, however, is expensive because much industrial engineering expertise is required. Individual worker motions must be measured precisely because any error or misjudgement will be multiplied many times by the time all the contract's operations and processes are complete. Consequently, predetermined leveled times are used mostly by contractors engaged in high volume production. These contractors repeat work operations over a relatively long time period, so they can afford the expense of relatively infrequently developing predetermined standards.

The detailed application of the techniques used in developing predetermined leveled times are beyond the scope of this guide (see the bibli ography). In practice, development of an operation's leveled time via the predetermined standards system follows about the same steps as development via the time-study method, except that body motions instead of elements are measured and leveled.

Work-Sampling Techniques. The work-sampling technique, unlike the predetermined-leveled-time and the time-study techniques, is not based on continuous observations of several performances of one or a few carefully selected workers. It is based on random timings of randomly selected workers. Also, the timings of work samples are not of individual worker motions or elements of a work cycle. They are of an entire work cycle (an operation or a process), with accurate leveling difficult, if not impossible.

When work-cycle times are long, the work-sampling technique usually is used so that the contractor can minimize the time and expense required to measure and to evaluate work-cycle performance. But when work cycles are short and will be repeated many times during the contract's fulfillment, work-sampling may be too imprecise for accurate estimates. The predetermined-leveled-time and time-study techniques, if properly used, produce more accurate results from the timing of one or a few work cycles than work-sampling produces. To develop reliable standard times for short work cycles, more time and money could be spent taking enough work samples to ensure statistical reliability than would be spent if the other techniques were used.

Allowances

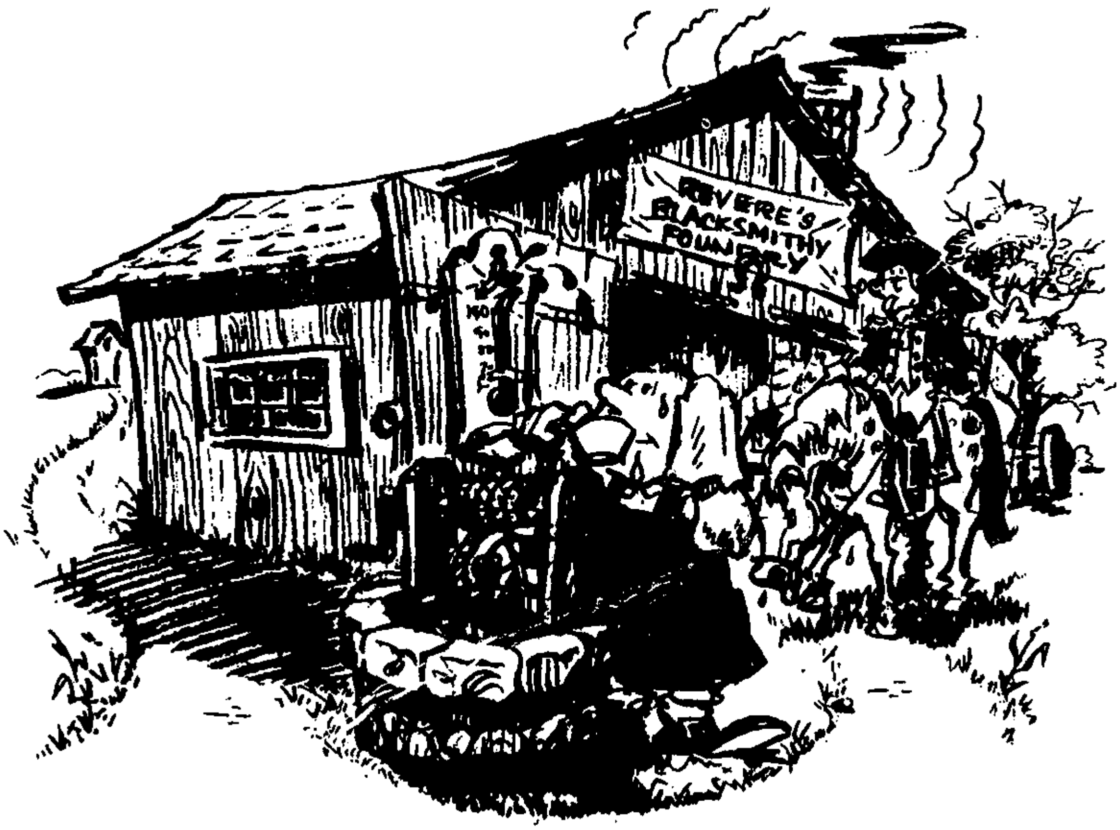
If operators could work without interruption, leveled time would be standard time. But uninterrupted work is unlikely, and when determining how long an operation or process should take, allowances must be made for reasonable interruption. The two basic allowances are the personal, fatigue, and delay (PF&D) allowance and the special allowance.

Allowances may be calculated for each time study with the data accumulated over a period of time and average allowances developed. Most contractors, however, keep on file a percentage allowance calculated by sampling the interruptions that normally occur in their facilities during the workday. Generally, such an allowance would be validated annually through work-sampling.

PF&D Allowance. The singular term "PF&D allowance," which actually encompasses three allowances, is used because the three allowances usually are considered as one component of standard time. For example, a personal allowance of 5 percent, a fatigue allowance of 5 percent, and a delay allowance of 5 percent would be combined to become a PF&D allowance of 15 percent. A reasonable combined PF&D allowance, under normal conditions, would be no greater than 20 percent.

Personal Allowance. The personal allowance is for compensating for the time required by the average operator to take care of such personal needs as getting a drink of water, going to the restroom, and washing his hands. A personal allowance normally does not include rest periods that are specified in collective bargaining agreements. These rest periods are considered time for recovery for fatigue. Some contractors, however, do include these rest periods in their personal allowance. Lunch periods are not included in PF&D allowances.

The personal needs of employees vary with their physical makeup, so contractors determine the average time taken by employees to take care of their personal needs. This is done by sampling several workers' personal time requirements for a workday and dividing by the number of



THE PERSONAL ALLOWANCE COVERS THE LOSS IN PRODUCTIVE TIME WHEN WORKERS MUST ATTEND TO PERSONAL NEEDS.

workers. Note that employees need more personal time than normal when the work is heavy or is done under unfavorable conditions (see R. M. Barnes, *Motion and Time Study*).

Fatigue Allowance. The amount of time that workers need to recover from fatigue is complex and controversial; even medical authorities disagree about it. And according to Prof. A. G. Anderson, "...industrial operations as carried on in a modern, progressively managed manufacturing plant do not subject the workers to undue fatigue, either physical or mental,...fatigue is not a factor tending to limit production...."*

Fatigue does have little effect in most industries today because the workday is shorter than ever and machinery and automation have made work easier than ever. Work is less hazardous, so mental fatigue resulting from fear has been reduced.

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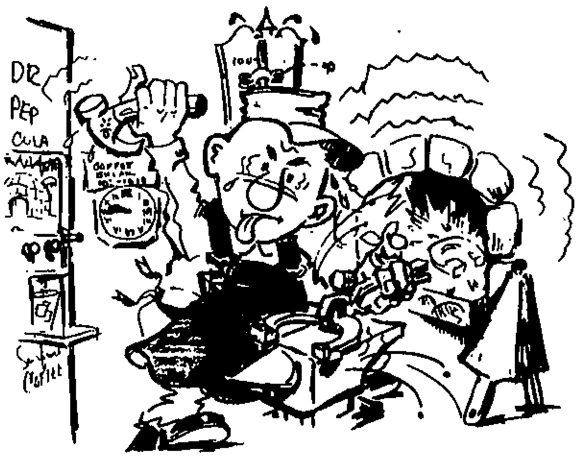
*A. G. Anderson, "A Study of Human Fatigue in Industry," an abstract of a thesis, University of Illinois, p. 22.



SCHEDULED REST PERIODS PERMIT WORKERS TO RECOVER.

At present, the effects of fatigue can be measured only by observing output declines as the workday passes, and even then we cannot be certain that the decreased production results from fatigue. It may be because the worker is tired, or it may be because he is sick or just does not want to work.

Despite any controversy over fatigue, the Government accepts fatigue allowances when contractors can show that their personal allowances are insufficient for complete fatigue recovery. A guide to determining how much rest a worker should require is that an average worker normally needs as much time to recover from a significant energy expenditure as he spent during the significant energy expenditure. Handling between 30 and 50 pounds of material would cause a "significant energy expenditure." The time needed to recover from fatigue varies among individuals, but companies usually develop a companywide fatigue allowance.

To control fatigue recovery, companies prohibit work during the organized rest periods, which may be included in either the personal allowance or the fatigue allowance (but not both). Typically they provide one midmorning and one midafternoon rest period, with each lasting from 5 to 15 minutes, depending on the type of work. The 10-minute rest period is most common. Also, unassisted workers are not allowed to handle material weighing more than 50 pounds.

There is a growing tendency in industry to design work efforts so that fatigue is minimized and to limit fatigue recovery time to organized rest periods. Nevertheless, in some types of work the rest periods may be insufficient. The worker may need short breaks between operations--so short that they can be observed only through time studies. Workers in machine shops, foundries, loading and unloading docks, warehouses, and other material-handling facilities with harsh environmental conditions or requiring strenuous work may need an allowance of up to 5 percent of the workday besides the time allowed in rest periods.

Delay Allowance. This allowance is for unavoidable, predictable delays. Avoidable delays result either from operator failure to exercise reasonable skill or judgment or from mismanagement, as evidence by inadequate or improper instructions or supplies. Avoidable delays should not be included in a delay allowance because they should not happen. Such unavoidable delays as those caused by power failures, major machine breakdowns, and interruptive acts of nature should not be included in a delay allowance because they are *unpredictable* in both frequency and duration and cannot be considered normal. Lost productive time resulting from such unpredictable delays usually is compensated for in overhead rates.

Delays that can be included in a delay allowance are the unavoidable, predictable, nonproductive time periods needed to replenish material at the *immediate* work station, to reject occasional substandard parts, to make minor repairs to tools and equipment, and to receive instructions. In some plants, the morning startup, which includes oiling the machines, and the end-of-day cleanup, which includes sweeping, are considered unavoidable delays to be included in the PF&D allowance. In other plants, these delays are considered part of the special allowance. The kind and amount of delays should be determined by periodic studies.

Three to 8 percent--14 to 38 minutes--of an 8-hour workday is a reasonable range for delay allowances, with 5 percent being an acceptable average. Delays included in the PF&D allowance should not be included in a realization factor or in a special allowance.

Mathematics of the PF&D Allowance. A PF&D allowance of 15 percent of the workday means that 72 minutes of each 8-hour day are nonproductive.

To find this allowance, divide the PF&D minutes by the total minutes in the working period, which are 480 minutes for an 8-hour day. If observations show that the average daily PF&D time is 72 minutes, the 72 minutes divided by the 480 minutes of an 8-hour workday is 0.15, or 15 percent. Fifteen percent of each workday can be allowed for PF&D.

But sometimes a PF&D allowance of 72 minutes an 8-hour workday is not considered a 15 percent PF&D allowance. Many contractors consider the PF&D allowance to be a percentage of leveled time. A 72-minute daily PF&D allowance means that 9 minutes of every hour in the workday are nonproductive. A contractor would be paying for 60 minutes of work each hour, but he would be receiving only 51 minutes of actual work. The time for which he is paying is 17.6 percent more than the time he receives in labor.

By subtracting a daily PF&D allowance of 72 minutes from the workday's 480 minutes you will derive a daily "leveled" time of 408 minutes. By dividing the 408 minutes by 72 minutes, you will find that the PF&D allowance is 17.6 percent of the leveled time. If you know an operation takes so many minutes in leveled time you can find the standard time (minus any special allowance) for that operation by multiplying the leveled-time minutes by 0.176 (17.6 percent) and then adding the result to the number of minutes.*

*Another method is to multiply the number of minutes by 1.176, or by 117.6 percent, which represents 100 percent of the leveled time plus the PF&D allowance, which is 17.6 percent of the leveled time.

Special Allowance. A special allowance can be used to allow for delays not included in the PF&D allowance or realization factor. Typical delays included in this allowance are such unavoidable delays as time for cleaning and oiling machines and cleaning the work area, if these duties are regular assignments of the direct manufacturing laborers to which the particular standards apply.

Special allowances are based on work interruptions and are calculated in about the same manner as PF&D allowances: first they are determined first as minutes; then they are converted to a percentage. Because the cost of these delays should be applied equally to all affected contracts, the contractor usually applies his special allowance as a constant percentage to all applicable leveled times.

Special allowances can be included in the PF&D allowances and applied with them; they can be included in realization factors; or they can be applied as a separate allowance. If a special allowance is applied separately, it can be computed as a percentage of the workday leveled time just as we did for the PF&D allowance, or it can be computed as a percentage of leveled time plus the PF&D allowance.

Some special allowances are *applicable only to specific operations* and may be applied when:

(1) A special job cycle allowance is justified. F. C. Hartmeyer, in his *Electronics Industry Cost Estimating Data*, maintains that as the job cycle grows larger, assembly efficiency decreases. He says (page 227) that "even after the learning period is complete, the operator installing 100 different wires will take longer per wire than one installing 10 wires." He further quantifies this allowance in terms of minutes per work cycle.

(2) There is an existing leveled time for an operation, but some means is needed to allow for differences in methods or material. For one operation, a contractor may keep in his data files different leveled times to allow for differences in working conditions or methods. But if a new contract calls for some modification in method, which is accounted for in none of the existing leveled times, and if time or industrial engineering costs discourage development of yet another leveled time, the contractor can apply a factor to compensate for the difference between an existing leveled time and the "leveled time" under the newly proposed method.

Suppose a contractor develops a leveled time from time studies for drilling a series of 1/8-inch-diameter holes through a 1-inch-thick aluminum plate while sitting at a work station and using a conventional hand-operated electric drill. This leveled time would prove inaccurate if the worker had to drill the same amount of holes in the same aluminum plate if the plates were in an overhead position attached to a major assembly. This position would be similar to drilling straight up into a ceiling with the arms fully extended. The contractor would allow additional time for this method to compensate for both additional elemental time required and additional fatigue encountered. In this instance, the allowance, probably expressed as a percentage to be applied to the existing leveled time, would be based on an engineering judgment rather than on time studies because of the time and costs involved.

Note that if the existing leveled time had been developed from predetermined standards, a change in method probably could be compensated for by the substitution of other predetermined standards. Predetermined standards for various body movements and positions are widely available, and an operational leveled time consisting of predetermined standards can be readily modified without resort to estimated special factors. Note also that even if the prescribed labor method in the initial assumption did not change but the *material* was changed from aluminum to steel, the leveled time for the actual drilling (only) would have to be adjusted. This presumes that the same drill bit was used for both metals.* This allowance, as well as the allowance for method change, may be termed a "complexity factor" or a "manufacturing allowance" or, for that matter, whatever the contractor wants to call it.

Once developed for a given task, operation, or process, ordinarily a leveled time remains constant unless the prescribed method changes. Depending on management policy, no change in leveled time is likely until it becomes from 3 to 5 percent inaccurate. This change in leveled-time value may result from a single method change or from an accumulation of small, subtle changes.

The Allowances and Leveled Time "Tightness." "Tight" leveled times include little time not used by a worker in actual production of the end item. The time a worker consumes resting, receiving instructions, and servicing his machine is confined to the allowances, factors, and curves.

Tight leveled times usually are applied to mass-production and wage-incentive conditions because production is carefully monitored during these conditions. Close monitory is required in mass-production conditions because the cost of one item's production will be multiplied many times and accuracy in billing must be demonstrable.

"Loose" leveled times, on the other hand, include some time not used by a worker in actual production of the end item. In a job shop, contracts do not call for the production of many items and conditions are not as predictable as in a mass-production shop. Workers frequently have to reset their machinery for different kinds of jobs and their tools

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*See appendix B.

usually are less sophisticated and efficient than those in mass-production shops. Production usually cannot be monitored closely in a job shop.

If a contractor has used tight leveled times, he probably has compensated himself for nonproductive time in higher than normal PF&D and special allowances and realization factors. If a contractor has used loose leveled times, his allowances and factors should be less than normal. Although tight leveled times are expected for mass-production conditions and loose leveled times are expected for job-shop conditions, these expectations do not occur always (see table II-D-1).

Table II-D-1 shows that production time is greater in a job shop than in a mass-production shop, which is reasonable. The setup and run times for the job and mass-production shops, however, are unreasonable. The contractor has used his PF&D and special allowances and the realization factor to compensate for the unusual tightness of the job-shop leveled time and the unusual looseness of the mass-production shop leveled time.

STANDARD TIMES DEVELOPED FROM OUTSIDE DATA

In developing standard times, a department within the contractor's organization can use standards and standard-related data from other sources. Six other sources are:

(1) Textbooks
(2) Industry magazines and pamphlets
(3) Individual equipment specifications
(4) Competitors
(5) Other departments or divisions
(6) Central group that develops companywide standards

Textbook data may be "raw operational data," which usually are tabular and represent recommended optimum operational time. Typical of this type of data are tables that deal with such operations as drilling, milling, and grinding. These tables include information about feed speeds, tooling, and performance time. In addition, textbooks concentrating on a single industry's productive processes, such as F. C. Hartmeyer's *Electronics Industry Cost Estimating Data,* are available. Although some tables include recommended job setup times, they usually do not include PF&D and special allowances. Other textbook data are "weighted average standards or norms," which include not only averages of raw operational data, but average standard times for performing average tasks. These data may be in either table or nomograph form.

Other sources of published standards and norms are industry magazines, pamphlets, and published texts of seminar presentations. The information contained in these publications usually is limited to the

Table II-D-1. Unexpected Tight and Loose Leveled Times*

Time Values	Tight Leveled Time in a Job Shop	Loose Leveled Time in a Mass-Production Shop	Reasonable Leveled Time in a Moderate Production Shop
LEVELED TIME			
Setup Time	36.0 min	56.0 min	45.0 min
Run Time per Part	3.8 min	4.2 min	4.0 min
ALLOWANCES			
Special Allowance	20%	10%	15%
PF&D Allowance	20%	10%	15%
STANDARD TIME			
Setup Time	51.8 min	61.7 min	59.5 min
Run Time per Part	5.5 min	5.1 min	5.3 min
REALIZATION FACTOR	1.20	.95	1.05
BID TIME FOR PRODUCING FOUR PARTS+	88.6 min	78.0 min	84.7 min
BID TIME FOR PRODUCING 500 PARTS+	3362.2 min	2481.1 min	2845.0 min

*All values are for illustration only.

+The special allowance is a percentage of leveled time added to leveled time. The PF&D allowance is a percentage of leveled time plus special allowance and is added to them, which results in a standard time. Bid times are determined by multiplying the standard run time per part by the number of parts, then adding the standard setup time to determine the standard time for producing the specified number of parts, and, finally, multiplying this value by the realization factor.

experiences of only one organization and contrasts with textbook information, which usually is derived from several organizations.

Individual equipment specifications, usually published by the manufacturer of the equipment, tend to be biased to promote equipment sales. Their acceptability depends on (1) whether the material represents optimum or average performance and (2) whether the quoted time is pure machine-controlled time or overall operation time including worker functions.

Although most organizations publish their cost-estimating data for in-house use as proprietary information, this information can and does become known throughout industry. Competitors are prone to use each other's data in their own estimating systems, thereby reducing the cost for developing and maintaining their systems. Although this may seem to suit Government preferences for price competition, competitors' data should be used only when consideration is given to differences among companies' production methods.

In some organizations, some departments or divisions are ahead of others in developing standards and cost-estimating techniques, and sometimes one group will use data from another. They should be used with extreme caution, because standards and norms developed in one environment may be either reasonable or unreasonable for use in another environment, depending on such variables as equipment, work flow, and working conditions.

Some contractors develop intracompany or companywide labor standards, which can be applied anywhere in the plant. They include leveled times, allowances, and standard times, all of which should be used with the same caution due than interdivisional or interdepartmental data.

No matter their source, standard times should consist of certain components applied in a logical way. The usual components of standard time are shown in figure II-D-5.

PROJECTING BID TIMES FROM STANDARD TIMES

Standard performance seldom can be maintained throughout production because unpredicatable delays do occur, because all workers are not "average-skilled," and because workers seldom begin at or maintain standard performance. Moreover, although predictable delays usually are included in standard times, a contractor can account for these interruptions by other acceptable means.

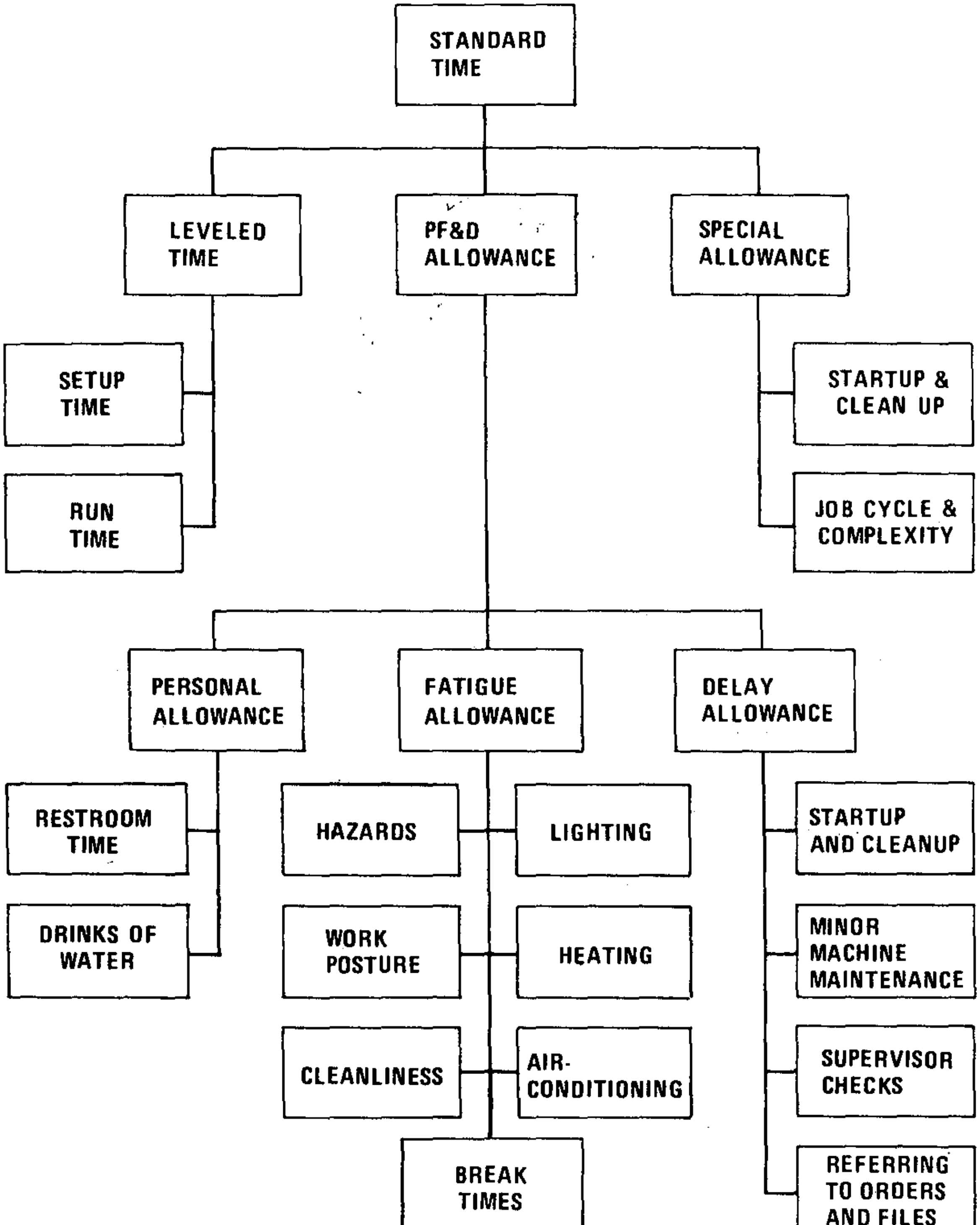


Figure II-D-5. Standard Time Components

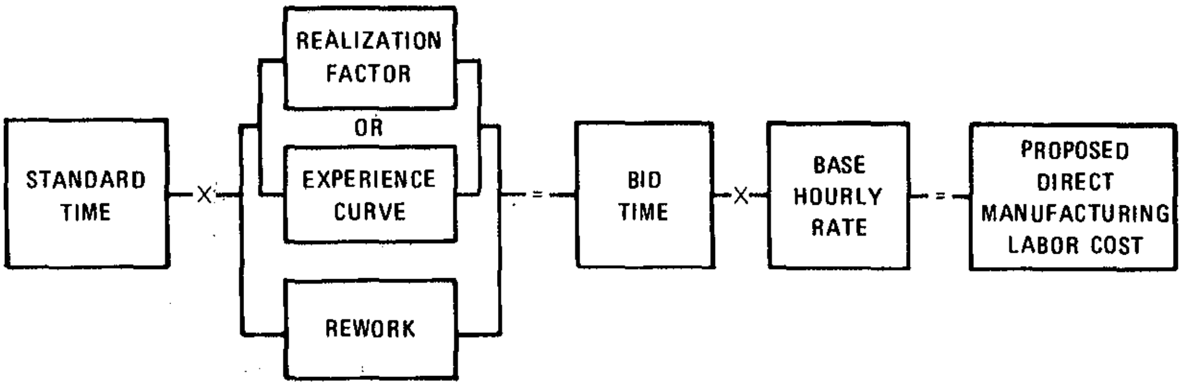


Figure II-D-6. Using Labor Standards To Estimate Direct Manufacturing Labor Costs

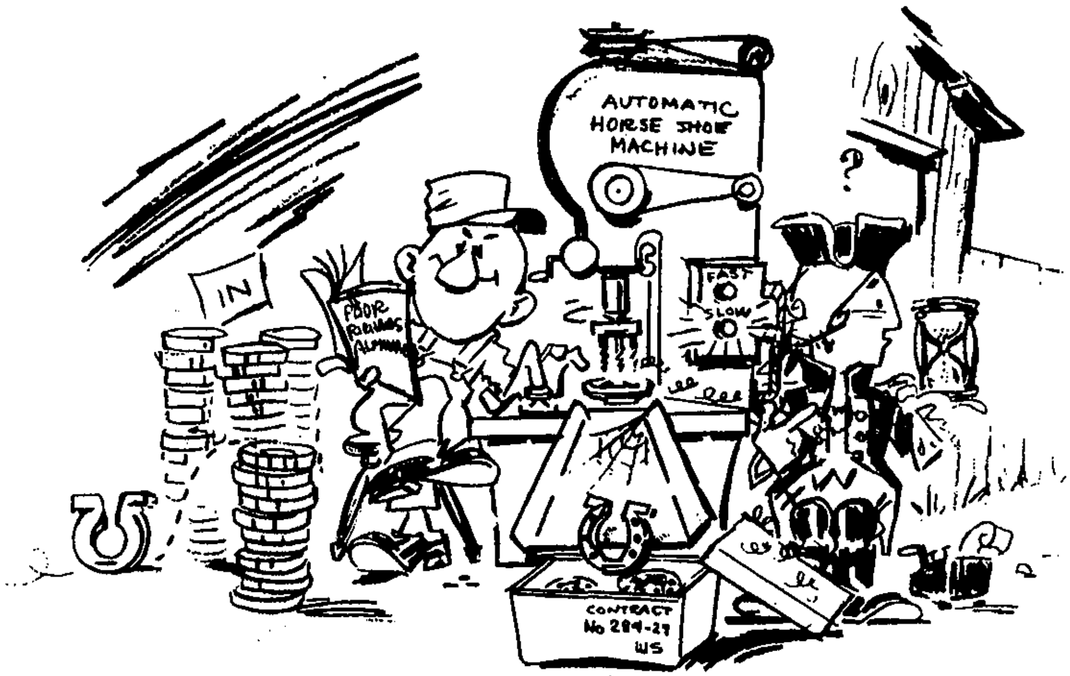
Direct manufacturing labor cost is estimated by multiplying the hours of "bid time," not standard time, by the base hourly wage rate. The Government would like to pay for operations and processes completed in their standard times--their "should-take" times--but it acknowledges that standard performance may not be achievable. It accepts "bid times" that exceed standard, so long as the gaps between standard and proposed performance are reasonable and the contractor can support them.

Even when actual times in themselves cannot be accepted as a bid times, they can be used with standard times to project bid times. Once the standard time is determined for an operation or process, the bid time for that operation or process can be determined by formulas that project the difference the contractor historically has maintained between standard and actual performance.

These formulas are realization factors, efficiency factors, experience curves, and rework factors. Figure II-D-6 shows the application of these factors.

Realization Factors

A realization factor is the ratio of actual time to standard time. For example, if a process's standard time were 1 hour, and 1-1/2 hours actually were spent on the process, the realization factor would be 1.50. You derive 1.50 by dividing the actual time (1-1/2 hours) by the standard time (1 hour). A realization factor of 1.50 means that the actual time required for a process is 50 percent more than the standard time. Multiplying the realization factor by the standard time should give you the bid time.



THE REALIZATION FACTOR COVERS THE DIFFERENCE BETWEEN STANDARD TIME AND BID TIME.

A contractor determines realization factors by comparing actual performance with standard time. That is, the contractor records the time actually spent to perform specific activities. Then, for each activity, he divides his recorded actual time by the predicted standard time for the activity. By averaging his historical realization factors, he can determine an average realization factor that can be used to calculate the difference between standard and "bid" performance.

If the contractor needs to project a realization factor for a type of work with which he lacks actual experience, he could project a realization factor based on trial samples of the activities to be performed. That is, by taking sample timings of his workers' performance of specific activities, the contractor can determine realization factors for those activities by comparing the actual times of the sample performances with the standard times for those activities.

Realization Factors and Unpredictable Delays. Some delays may not have been included in a PF&D allowance because foreseeing them was impossible. These delays can result from such acts of nature as thunderstorms and floods, from such accidents as fire, and from equipment failure.

Although these delays probably could not have been anticipated, the recurrence of many of them could be prevented or minimized, such as by fire-prevention or replacing obsolete equipment.

Realization Factors and PF&D Allowances. We have defined standard time as leveled time (working time only) plus PF&D and special allowances, but the contractor's definition of standard time may not completely agree with ours. His standard time may not include allowance that you have included in your PF&D allowance. For example, your PF&D allowance may include a fatigue allowance for 2-minute rest periods that a worker lifting heavy objects takes throughout the workday. The contractor, however, may have included an allowance for the rest periods in his realization factor rather than his PF&D allowance. Although the contractor's method is not ordinary, you should accept it if it produces reasonable results.

Suppose a contractor says his realization factor is 1.26. You determine this means that 8 hours is required for work that should be produced in a standard time of 6.35 hours, which probably is unreasonable. But if the 1.26 realization factor includes PF&D (15 percent) and special (4 percent) allowances that are cumulatively 20 percent of the contractor's standard time of 6.35 hours, and standard time in reality is leveled time, it would be reasonable. If you add the 20 percent for allowances to the 6.35 hours (6.35 hours times 120 percent), you get a standard time 7.62 hours. The realization factor of an actual time of 8 hours to a standard time of 7.62 hours is about 1.05.

Efficiency Factors

Some contractors use efficiency factors rather than realization factors. An efficiency factor, the mathematical reciprocal of a realization factor, is derived by dividing standard time by actual time. Suppose eight units should be produced in an 8-hour day (1 standard hour per unit) but only six units actually are produced. If you divide the 6-hour standard time by the 8-hour actual time you will get an efficiency factor of 0.75, or 75 percent. A 75 percent efficiency factor is equal to a 133 percent realization factor. An efficiency factor of 75 percent means that the contractor's workers are producing 75 percent of what they are supposed to produce in standard time.

PERFORMANCE AND EXPERIENCE ARE RELATABLE.

Experience Curves

Another method for projecting the difference between actual and standard performance is the experience curve. The basic theory of the experience curve is that performance improves with each repetition

A WORKER LEARNS AS HE WORKS. . .

of an operation or process. A worker learns as he works; as he repeats an operation, his efficiency increases and his direct labor time input per unit declines. And besides the effects of individual worker learning on production, an experience curve can be used to account for the effects of the following:

- Development of tools, machines, and methods that are more efficient than the ones used when contract work began

- Solution of engineering problems, resulting in stabilization of design

- Use of subcontractors who can produce components more cheaply than the contractor can

- Simplification of designs

- Improvement of material procurement and handling methods

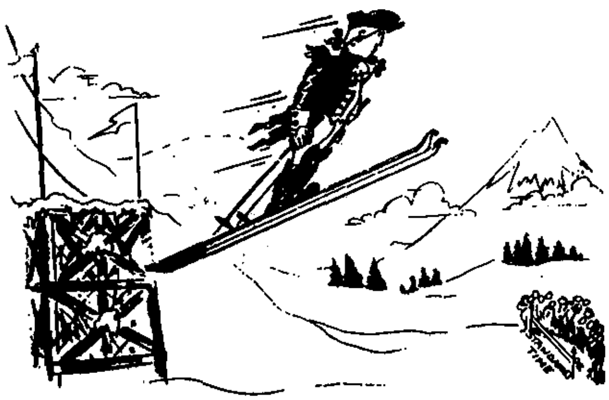
- Management improvements, such as simplification of procedures, installation of sophisticated tooling, and automation

T. P. Wright wrote that the rate of improvement is predictable.* He said that the cumulative average labor cost for any quantity of product decreases by a constant amount as that quantity of product doubles.+ (Applying his hypothesis to time rather than money, this means that if 1000 hours are required to produce the first unit, the cumulative average time to produce each of the first two units would be 800 hours,

AS HE REPEATS AN OPERATION, HIS EFFICIENCY INCREASES. . .

**Journal of the Aeronautical Sciences, February 1936.*

+Both unit and cumulative total curves have been developed from this hypothesis and are discussed in appendix A.



AND HIS LABOR INPUT PER UNIT DECLINES.

each of the first four units 640 hours, and so on, if the constant rate of improvement is 20 percent for each doubling of the numbers of units produced. When the rate of improvement is 20 percent for each doubling, the *slope* of the experience curve is said to be 80 percent. Figure II-D-7 illustrates Wright's hypothesis. Table II-D-2 shows three different slopes developed from this hypothesis.

The Experience Curve and Standard Time. All experience curves eventually cross standard. That is, regardless of how much time or money is spent to produce the first unit, inevitably the time will come when a unit is produced in standard time and even in less than standard time because the worker output can and does exceed standard output. Theoretically, as long as the contractor continuously produces a type of product, each unit of product will take less time to produce than did the previously produced units of that product. In real life the curve will "flatten out" shortly after it crosses a standard that represents normal or average production. Figure II-D-8 illustrates this point.

Table II-D-2. Comparison of an 80, 85, and 90 Percent Wright Cumulative Experience Curves

Unit	80% Slope	85% Slope	90% Slope
1	1000	1000	1000
2	800	850	900
4	640	723	810
8	512	614	729
16	410	522	656
32	328	444	590
64	262	377	531
128	210	321	478

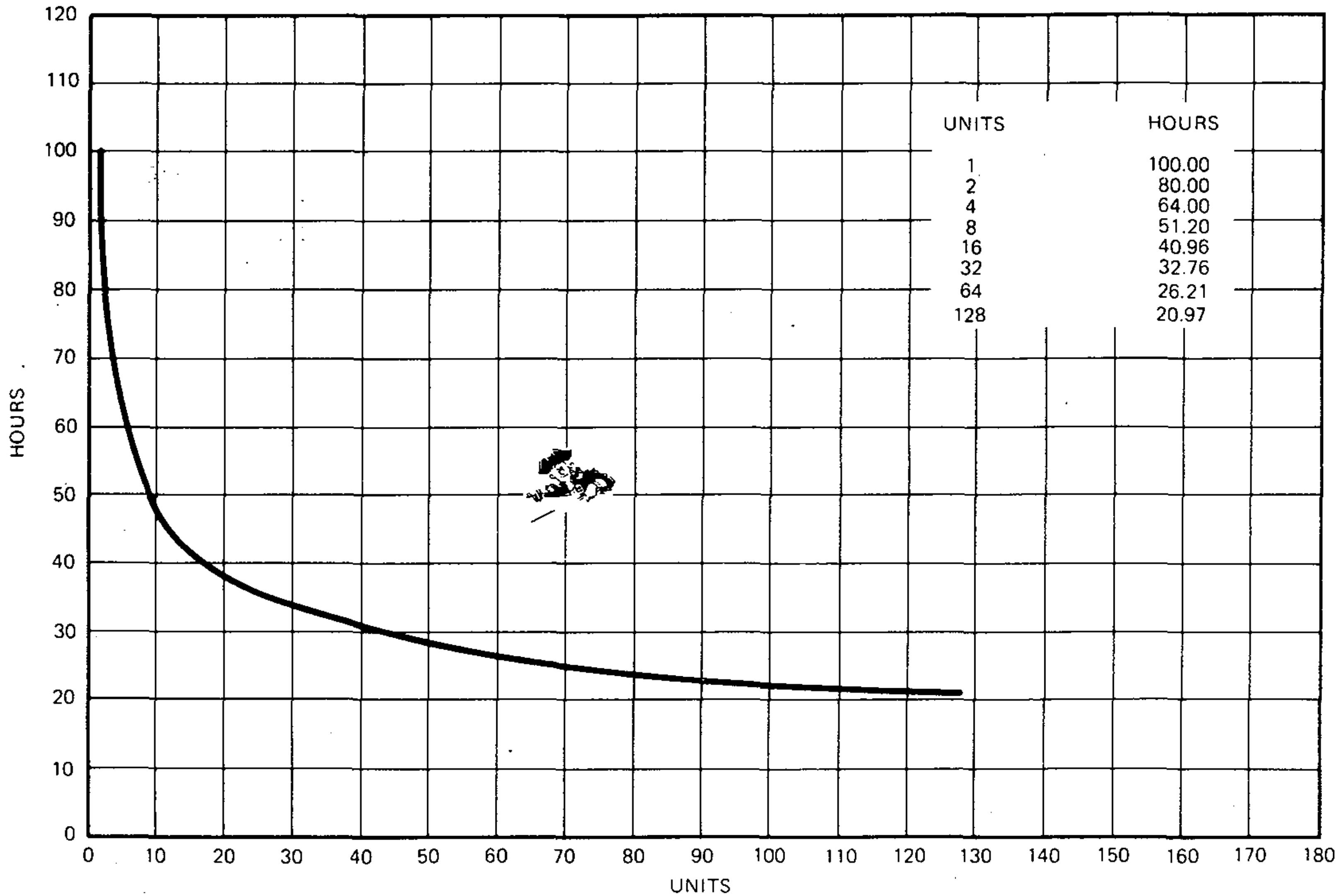
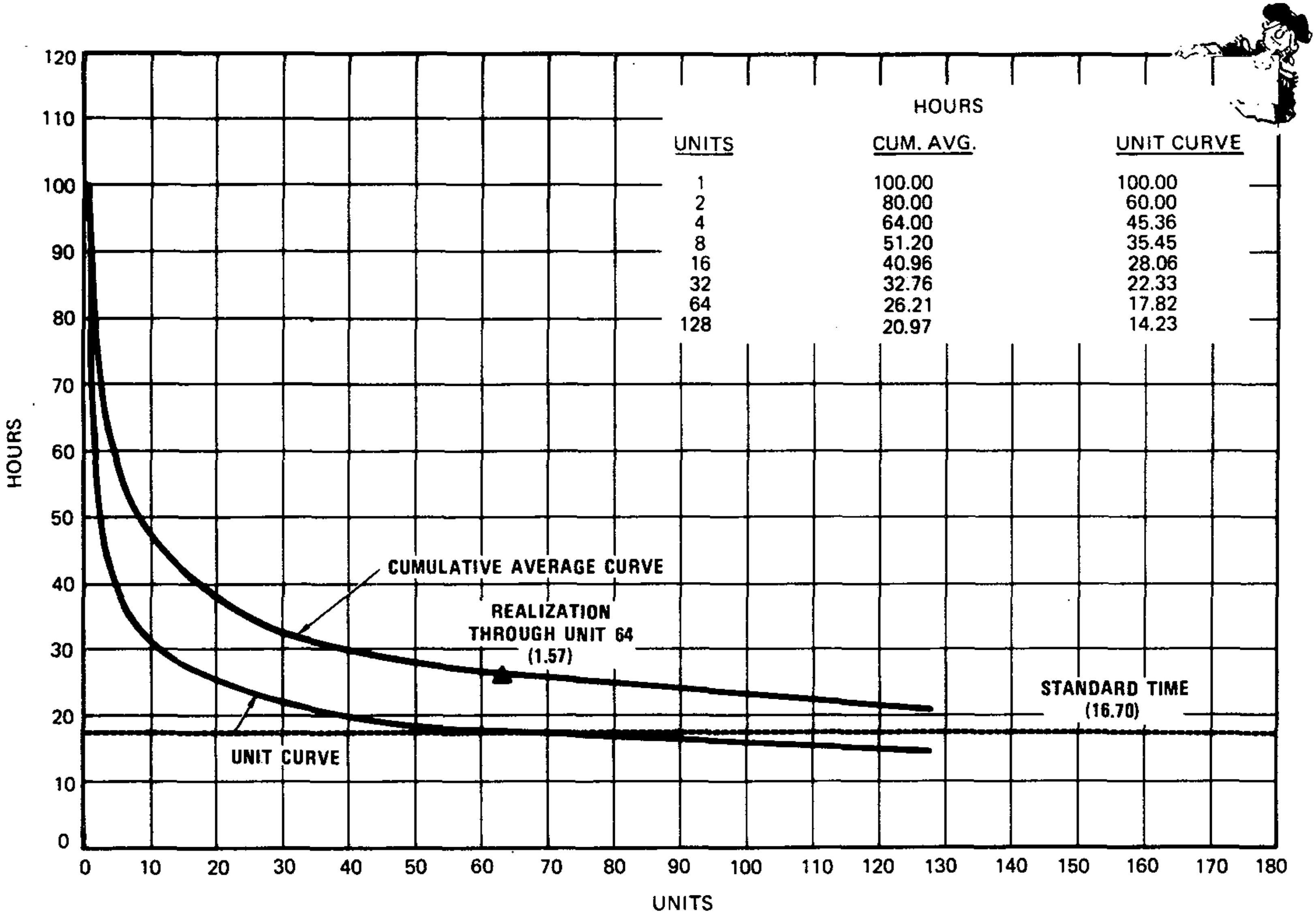
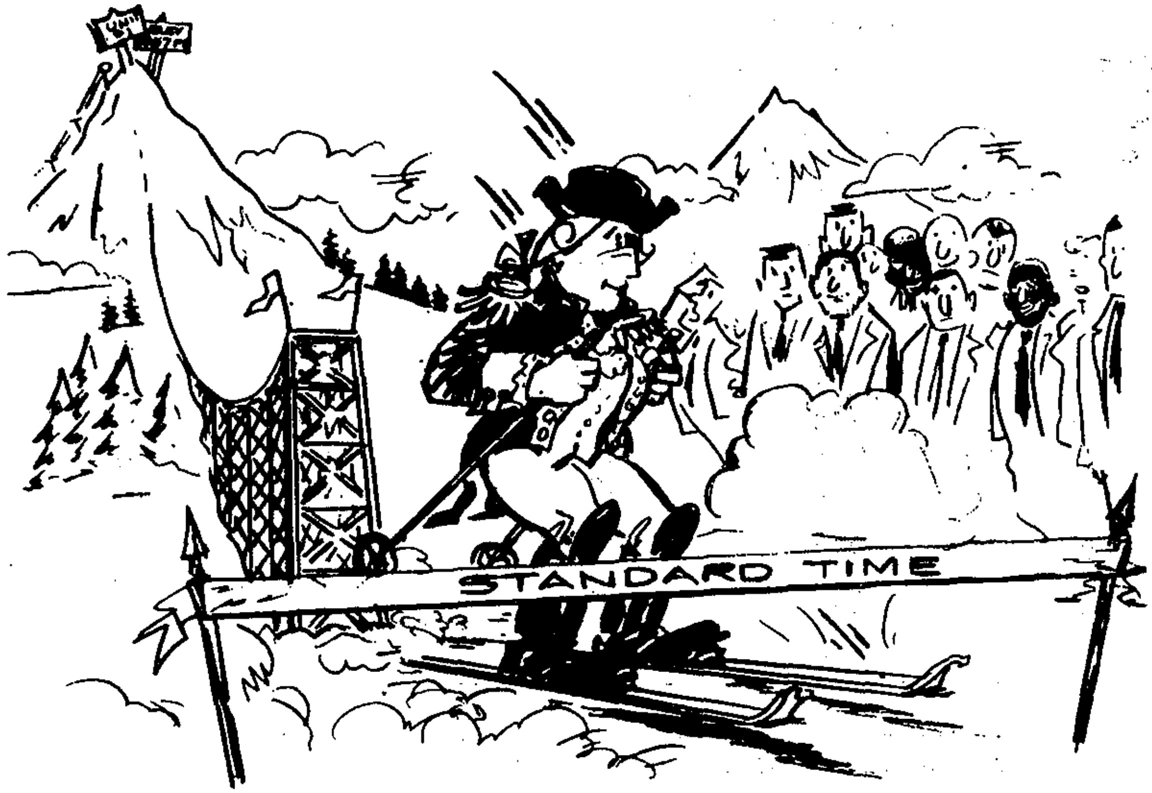


Figure II-D-7. Eighty Percent Cumulative Average Curve--Wright Method



HOURS		
UNITS	CUM. AVG.	UNIT CURVE
1	100.00	100.00
2	80.00	60.00
4	64.00	45.36
8	51.20	35.45
16	40.96	28.06
32	32.76	22.33
64	26.21	17.82
128	20.97	14.23

Figure II-D-8. Eighty Percent Cumulative Average and Unit Curves--Wright Method



ALL EXPERIENCE CURVES EVENTUALLY CROSS STANDARD TIME.

The Wright Method and the Crawford Method. Because the Wright Method and the Crawford Method are the two most commonly used methods for plotting experience curves, we will compare these two methods.

Under the Wright Method, the *cumulative average* time or cost for any number of products decreases by a constant amount as the number of products is doubled. That is, if the first item produced cost $1000 and a second item is produced, the cumulative average cost of the two items would be $800 if you were using a 80 percent curve slope. If four items were produced and you used a 80 percent curve, the cumulative average cost of all your units would be $640 ($640 is 80 percent of $800).

Under the Crawford Method, the curve is based on *unit costs*, which decrease by a constant amount as the number of units produced doubles. Tables II-D-3 and II-D-4 compare these two methods.

Table II-D-3. Comparison of the Wright Method and the Crawford Method, Unit One Common to Both

Unit	Wright Unit Curve	Wright 80% Cumulative Curve	Crawford 80% Unit Curve	Crawford Cumulative Curve
1	1000	1000	1000	1000
2	600	800	800	900
3	506	702	702	833
4	454	640	640	785
5	418	596	596	747
7	371	534	534	691
10	329	477	477	632
20	261	381	381	524
30	228	335	335	467
50	193	284	284	402
100	154	227	227	327
500	92	135	135	199

Table II-D-4. Comparison of the Wright Method with the Crawford Method, Unit 1000 Cumulative Average Common to Both

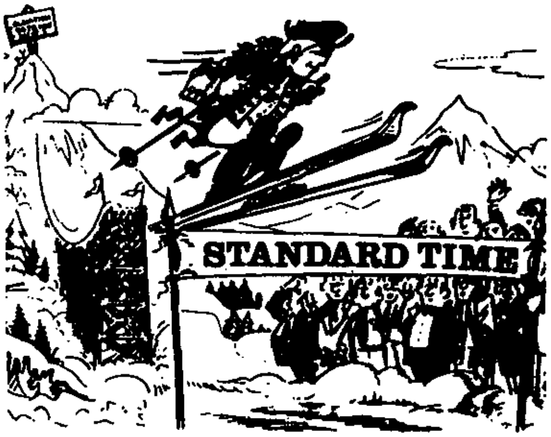
Unit	Wright Unit Curve	Wright 80% Cumulative Curve	Crawford 80% Unit Curve	Crawford Cumulative Curve
1	1000	1000	679	679
2	600	800	543	611
3	506	702	477	566
4	454	640	435	533
5	418	596	405	507
7	371	534	363	469
10	329	477	324	429
20	261	381	259	356
30	228	335	227	317
50	193	284	193	273
100	154	227	154	222
500	92	135	92	135
1000	73	108	73	108

KNOW YOUR METHOD.

As shown in the tables, the Crawford Method also includes a way to compute cumulative averages. But, although *the Wright Method's cumulative average cost is equal to the Crawford Method's unit value* when the same number of units is produced, *the Wright Method's unit value is not equal to the Crawford Method's cumulative average value.* Also, *the Wright Method's unit value is not equal to the Crawford Method's unit value,* and *the Wright Method's cumulative average value is not equal to the Crawford Method's cumulative average value,* regardless of the unit one, the slope, or the number of units produced. (For an elaboration on these concepts, see appendix C.)

The Slope of the Curve. The slope of the experience curve has the same effect regardless of whether you use the Wright Method or the Crawford Method: the steeper the slope, the greater the rate of reduction after unit one. When using the Wright Method, for example, if you assume a unit-one cost of $1000 with a 90 percent slope in the experience curve, when 64 units are produced the cumulative average cost will be $531. If you apply an 85 percent slope to a unit-one cost of $1000, when 64 units are produced the cumulative average cost will be $377 (see table II-D-2).

As you can see, when the number of units produced increases, the effect of a difference in the slope of the curve increases. In the above example, if the contractor arbitrarily chose a 90 percent slope rather than an 85 percent slope, his decision would increase the cumulative average cost of 64 units by approximately 41 percent.



THE STEEPER THE SLOPE, THE MORE RAPID THE DESCENT FROM UNIT ONE.

Unit One. Experience curves can be used to determine the number of direct manufacturing labor dollars or hours required to produce the proposed quantity. If the contractor knows how much time it takes to produce the first unit, and he knows how many units his workers must produce before they can produce one unit in standard time, he can plot an experience curve. By developing an experience curve, the contractor can determine how much time producing any one unit on the curve will take. (Note that the term "realization time" can be applied to points on the experience curve.) From this information the cumulative average hours for the proposed quantity can be obtained.

The time or cost required to produce the first unit, which the contractor must know to have a valid experience curve, can be determined either actually or theoretically. An actual unit one can be obtained from historical production records that reveal how much time or money was spent on unit one (the contractor should be able to prove these historical records are reliable). When historical records for unit one are unavailable, the contractor must be able to project a theoretical unit one. To project a theoretical time, the contractor must know (1) the performance time or actual cost of two or more units on the curve or (2) at which unit the curve crosses the standard and the rate of improvement in production. Knowing either of these, he can work back to unit one.

SELECT YOUR PEAK BASED ON HISTORICAL PERFORMANCE.

Automatic and semiautomatic operations require less "learning" than manual operations, so curves for automatic and semiautomatic operations should be less steep. Suppose a semiautomatic flow-solder operation with an average belt speed of only 2 feet per minute and loaded at the rate of one printed circuit board per foot (multiple boards per tray) will produce 120 boards per hour. Even allowing a combined PF&D allowance, special allowance, and rework factor of 133 percent of this leveled time, the machine will produce at a rate of 90 boards per minute. Because the machine normally requires a two-man crew, one to load and one to unload, a reasonable bid time per board would be 3 man-minutes.

Assuming that this machine has already been "debugged" the experience curve should be extremely shallow, possibly a 95 percent Wright cumulative average slope. There should be very little "learning" required from the workers and virtually none from the machine operation itself. Therefore, using 3 man-minutes per board at unit 1000, the maximum unit-one time would be only 5.0 man-minutes per board; at unit 100, only 3.6 man-minutes per board; and at unit 500, 3.2 man-minutes per board.

Suppose, now, that a contract calls for 25 harnesses consisting of ten wires each, with each wire being 3 feet long. The bid time for each of the 250 wires was 11.1 minutes per wire, which included cutting, stripping, identifying and laying up each wire and lacing the harness, but did not include attaching the connectors.

The bid time was arrived at by plotting a standard time (including all allowances) of 8.0 minutes per wire at unit 1000,* on an 85 percent Wright cumulative average curve.

When the contractor bid on a follow-on buy with no break in production, actual times were available through 200 wires. The actuals reaffirmed the 85 percent slope because the cumulative average time through unit 200 was 11.7 minutes per wire. Yet, on the second buy calling for 25 harnesses the contractor bid 8.4 minutes per wire instead of 7.7 minutes per wire. He had considered the actual at unit 200 to be the actual for unit 251 and had continued down the slope until unit 500 was reached. He had "straight-lined" the value at unit 200 through unit 250 and had violated the principle of extrapolation, which is described in appendix A. The result of the contractor's approach was a 9 percent inflation of the bid time.

Historical Data and the Experience Curve. Deciding the rate of improvement--the "slope of the experience curve"--*should never be arbitrary*. If the contractor has insufficient historical data of his own to develop an experience curve, he should use an experience curve based on the actual experience of other contractors or industry in general for that type of work. In other words, all experience curve slopes should be supportable by historical data.

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*If the contractor had a semiautomatic operation, he might have bid 3.0 minutes per wire at unit 1000. Contractors with automatic backplanners might bid 0.12 minute per wire at unit 1000.

Influences on the Experience Curve. Two influences on the development and use of the experience curve are whether or not the buy is a first buy and whether or not the buy will include breaks in production.

Although a contract may be a first buy from a contractor, chances are the end product will not be the first item the contractor ever made. In almost all cases, experience on similar items should provide enough historical data for projecting an experience curve for the first-buy item.

The production break is the time lapse between the completion of certain units of equipment and the beginning of a follow-on order or contract for identical units of equipment. This time lapse disrupts the continuous flow of production and necessitates revising an existing experience curve. In some procurements, follow-on orders and contracts are received prior to the delivery of the last units of the first order.

An example of a production break would be when circuit board assemblies have been completed and the assembly line has been shut down. To accommodate a new order, the assembly line would have to be reestablished. A break in production for awaiting material would be included when the experience curve for the particular production run was calculated. Such a break is not cause for revising an experience curve.

PRODUCTION BREAKS CAN BE OVERCOME.

No reliable method for compensating for learning losses stemming from production breaks has been established. Practice ranges from the use of perhaps unsupportable percentage factors to statements that no learning was retained after a production break. The total loss of learning is a common misconception that holds that worker learning is the only consideration in shop performance.

The loss of experience varies with the duration of the production break. If any impact from a production break exists, the greatest impact would be on direct labor learning and the least impact would be on methods improvements developed during the initial production run. A return to unit one as starting point for a follow-on order or contract is unreasonable.

When a multiyear buy or a follow-on contract entails no break in production, the experience curve developed for the initial quantity can be used for the succeeding quantities if it is reliable. But if actual performance recorded for the first quantity varies from the performance as predicted by the curve, a new curve should be plotted from the *actual* data and projections should be based on the revised curve.

Rework Factors

When a part or assembly is rejected in an inspection or test, if possible it is sent back for correction of its deficiency. Furthermore, some completed parts and assemblies must be reworked to incorporate minor design changes. Rework costs usually are included in the direct manufacturing labor estimate. Not to be included are costs for reworking items with design changes charged in engineering change proposals.

When a contractor bases his projected bid time on data derived from a standard cost system, a rework factor usually is applied as a percentage of leveled time. But generally when a historical cost system is used as the data base, the rework costs already included in the actual times eliminate the need for applying special rework factors. Contractors using a historical data base and maintaining separate rework data and applying rework factors risk making double-charges.

Although rework costs are usually included in direct manufacturing labor costs, a contractor might include them under "other costs" on the DD Form 633 because of his particular accounting system. Although this approach is rare, it is used.

A 1.05 to 1.07 rework factor applied to standard would be reasonable for electrical assembly work. A 1.03 to 1.05 factor would be reasonable for machine-shop operations. Note that rework time may be included in the realization factor. If so, it should not be compensated for again in a separate rework factor.

FABRICATION, ASSEMBLY, AND QUALITY CONTROL

For the most part, we take it for granted that we are talking about fabrication and assembly when we discuss direct manufacturing labor. Most man-hours in the direct manufacturing labor estimate are hours estimated for constructing the end product--fabrication and assembly hours. Quality control labor time, however, is usually a significant portion of the direct manufacturing labor estimate. Now, we are going to define fabrication and assembly, then spend a few pages focusing on the third category of direct manufacturing labor.

FABRICATION LABOR

The fashioning of parts from raw material is fabrication. This includes such machine-shop operations as sawing, perforating, drilling, punching, and lathe operations. In addition, depending on a contractor's management structure, welding, by definition an assembly operation, may take place in or near the machine shop and be considered a "fabrication" function.

ASSEMBLY LABOR

Most large plants have separate areas for assembling parts, subassemblies, assemblies, and subsystems to make the end products. Unlike fabrication, assembly usually takes place in progressive steps coming one after another--on an assembly line.

In electronics, "assembly" usually is considered to be the process by which components are manually inserted into, or attached to other components. Inserting a transistor would be an assembly operation within the process of assembling a printed circuit board.

QUALITY CONTROL LABOR

Quality control labor is the effort of setting up and tearing down inspection and test stations and carrying out the inspections and tests specified by quality assurance engineers. Some contractors estimate quality control time jointly with quality assurance time, both as engineering time. But most contractors consider quality control labor to be direct manufacturing labor and estimate it in much the same manner as they estimate other direct manufacturing labor time requirements.

Material Inspection

Before it is used, material coming into the contractor's plant must be inspected, either by the contractor or his outside supplier. "Government source inspection" does not relieve contractor and supplier from making required inspections.

MIL-Q-9858 and MIL-I-45208 discuss Government source inspection. These specifications say that the Government may elect at any time to visit a vendor's or subcontractor's facility to determine his conformance to contract requirements--that is, to inspect material at its source.

Government source inspection does not relieve the contractor of his inspection requirements, but if he is paying for rigid vendor inspection or lot certification in his purchase prices, he should not fully reinspect the purchased items coming into his plant. Perhaps a small degree of sampling inspection would be justified, but 100 percent inspection would not be.

There are two possibilities here for double-charges. The first would be the contractor's charging for inspection of incoming material when, in fact, he does not inspect the material because of his misconception of Government source inspection. The contractor then would be reimbursed for a cost not incurred. The other possibility would be the contractor's charging for vendor inspection in his material estimates and then charging for inspection of incoming material in his quality control estimates. In this case, the material charge for vendor inspection would be acceptable, but the contractor should not fully reinspect the material nor should he charge for it.

Aside from double-charges, the above two cases represent bad inspection practices. The first case represents underinspection because Government source inspection *would not free* the contractor from having to inspect the incoming material. The second case represents overinspection because a thorough vendor inspection *would free* the contractor from having to inspect all the incoming material.

Mechanical Inspection

After material has been subjected, by the contractor, to fabrication and assembly operations, it must be inspected to ensure it meets design specifications and can be used as an integral portion of a specific machine. When parts are fabricated in the machine shop, the time normally required for inspection of the finished parts generally amounts to between 7 and 9 percent of the hours used to fabricate the parts. In final assembly higher levels of the end product by hand, between 9 and 11 percent of the assembly hours typically would be required for inspecting the assembled items. Material incoming inspection may be part of material handling, material overhead, or a direct cost against fabrication or assembly. If the contractor accounts for this cost as a direct cost, a 5 percent increase in the above inspection costs can be expected.

Test

After material reaches an operational status, its performance eventually must be tested. The total time required for testing an end product or particular portion of the end product is based on:

- The time required to set up each test station

- The number of times each station must be set up and torn down

- The run time of each test

- The total number of units produced for which quality assurance is needed

- The percentage of produced units that must be tested to comply with the quality assurance specifications

- The number of units that can be tested simultaneously

- The degree of test automation

- How data are recorded

The time required to set up a test station depends on the test equipment and conditions needed. If electromagnetic isolation is required, for example, more setup time would be needed than if no such environmental condition were required. Complex equipment would have to be set up to produce such a condition.

The total setup time required for all tests of a product (subassembly, assembly, or system) can be determined by multiplying the time required for each setup by the number of times the test station must be set up.

A contractor can estimate the run time for testing a unit of product by using his own historical data, by developing standards, or by using published industrial standards. No matter how he does it, his unit run time estimates should include consideration of his test worker's experience, both in the past for similar testing and in the future for the experience that will be gained as the contract is fulfilled.

The number of units to be tested depends on the total number of units to be produced and the degree of quality assurance needed to ensure the customer gets an acceptable end product. The degree of quality assurance needed depends on how much, if any, quality assurance the contractor has demonstrated in producing the product for prior contracts. His quality assurance engineers will calculate a percentage factor that can be applied to the total number of produced units to determine the number of units to be tested.

If a tester can test more than one unit at a time, total test time should be shorter than if the units must be tested one at a time. Also, aside from simultaneous testing, some machines are faster than others. An automatically fed tester that can handle two units at a time should be faster than a manually fed tester handling two units together. When using an automatic tester, 2 minutes of test run time per card and 10 minutes setup time for the entire lot (including analysis and recording of data) would be typical.

Usually included in the total run time for testing a product is the time needed to record data pertaining to the success or failure of the unit tests. Test workers may not have the opportunity to stop their test apparatus after each unit test long enough to record data in all the necessary detail, so data recording time may not be included in unit test run time. But data must be recorded sometime, and data recording time is included in total test time. The labor time required to record test data depends on the amount of data to be recorded, the time required to extract the data, and whether the data are recorded manually or automatically.

The following examples give the approximate time durations of typical test operations in the electronics industry.

A. Test description: Manually test integrated circuit module per procedure and record reading.

Equipment: Vacuum tube voltmeter (VTVM); signal generator (supplies input); oscilloscope (receives output); power supply

Run time: 2.5 to 3.0 minutes per reading, which includes handling time and allowances. Equipment setup time and rework are not included in run time.

Note: For a large number of modules the above equipment should be integrated into an automatic test station, which would significantly reduce individual run times.

B. Test description: Manually test printed circuit board (up to 50 discrete components) per procedure.

Equipment: VTVM; Signal generator; oscilloscope.

Run time: 30 minutes, which includes rework of defective PCB's and their subsequent retest.

C. Test description: Perform programmed test of printed circuit board per procedure (for large quantities).

Equipment: Special automatic test set.

Run time: 6 minutes per completed card--overall time--or 10 "good" cards per hour.

Note: The hour consists of 20 minutes of actual test and data recording, two defective cards reworked at 15 minutes each, and 4 to 10 minutes to retest two cards that have been reworked.

D. Test description: Test and record 360-degree antenna pattern.

Equipment: Varies, but output is generally recorded graphically with rotating drum and ink stylus.

Run time: 15 minutes per test or four tests per hour.

E. Test description: Test system or unit for voltage standing wave ratio (VSWR).

Equipment: General-purpose electronic test equipment

Run time: 3 minutes per test including allowances; no rework or retest included.

F. Test description: Test high-voltage unit or system for impedance in megohms. Perform "Hi-Pot-Megger" test.

Equipment: General-purpose electronic test equipment.

Run time: 10 minutes per test or action.

Subsection II-E. "OTHER COSTS"

Depending on the contractor's accounting system, he may incur direct costs difficult to classify as direct material, engineering labor, or manufacturing labor costs. Such costs include special tooling; facilities; special test equipment; special plant rearrangement; preservation, packaging, and packing; spoilage and rework; warranty; automatic data processing; and travel. Costs such as these may be charged in the "other costs" line item on the DD Form 633. Now let us highlight special test equipment costs, "other material" costs, travel costs, and automatic data processing (ADP) costs.

SPECIAL TEST EQUIPMENT

Test equipment can be either capital (general-purpose) equipment or special test equipment. Capital test equipment is test equipment that can be used for more than one contract. It should not be treated as a direct cost item but treated as an overhead item. It includes such equipment as oscilloscopes and signal generators. Costs for capital test equipment depreciates over time, based on the equipment's expected life. Special modifications to capital test equipment can be accepted as direct costs.

Special test equipment is required for specific test requirements when capital equipment cannot do the job. Fabrication of special test equipment is a nonrecurring cost, much the same as the cost for fabricating a prototype model of the end product.

"OTHER MATERIAL" COSTS

Earlier, we defined indirect material as being not "obviously traceable" to the production of specific end products. Direct material, we said, is obviously traceable and generally becomes part of the end product. Some direct material, however, does not become part of the end product although it can be readily traced as a cost of producing that specific product. This material includes such low-cost items as special tooling, one-of-a-kind jigs and fixtures, spoilage if it was not already included in the material estimate, and such unique packaging material as specially shaped styrofoam protective inserts.

By placing items like the above in the "other costs" category, the contractor is saying he feels they belong in neither the direct material category nor an overhead account. Ordinarily, "other material" does not account for a significant portion of the total direct cost.

TRAVEL

Proposed travel in connection with the contract is an acceptable direct cost that usually is charged to the "other costs" account. Trips may be required for engineering design or program management coordination meetings with Government authorities, other program coordination meetings with other manufacturers associated with the overall project, negotiations with potential subcontractors, and source inspection of items purchased from outside suppliers.

In quoting travel expenses, the contractor should specify the round-trip distance of the trips, the number of persons to travel, transportation costs, per-diem expenses to cover overnight accommodations, and automobile rental fees and other associated costs. These figures, however, should not include any direct labor involved in the trips because such labor will be charged to the labor elements on the DD Form

COSTS FOR NECESSARY TRAVEL MAY BE INCLUDED IN THE PROPOSAL.

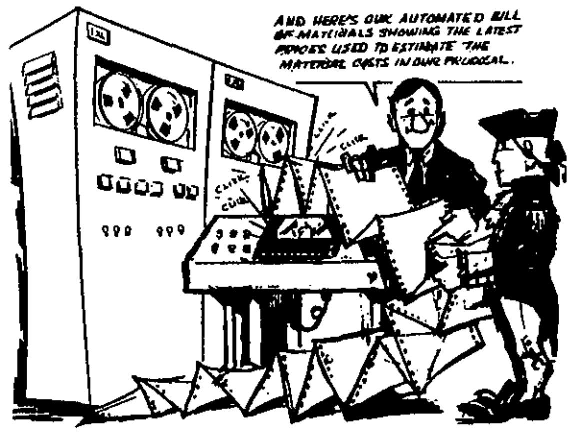
633. (Travel expenses are subject to DCAA audit.)

AUTOMATIC DATA PROCESSING

Automatic data processing has become so routine that it is likely to be charged in any production proposal. In the minimum application, it may be that only the company's cost-accounting and payroll systems are computerized, which will affect the proposal only in some increase to the overhead rates.

More commonly, however, the contractor uses ADP to control his material and inventory, to coordinate design configurations, and to schedule production. ADP also may be used to accumulate and evaluate quality assurance and reliability test data.

ADP labor may be charged as either a direct cost or an overhead cost. If it is charged as a direct cost, the keypunch hours, programming hours, and machine processing hours should be specified in detail.



AUTOMATED INFORMATION SYSTEMS USED ON CONTRACT ARE A DIRECT COST.

Section III. HOW TO EVALUATE DIRECT COST ESTIMATES

Subsection III-A. DIRECT COST ANALYSIS: AN OVERVIEW

As Walter Cronkite said in his old TV program, "You are there!" You are a technical evaluator, about to try your hand at direct cost analysis. You are enthusiastic, knowing that you and people like you are guardians of the U.S. Treasury, friends of the taxpayer, and, at the same time, helpers of the Government contractor, showing him how to increase his efficiency, thus his productivity, thus his profits.

You know the basic terms and procedures contractors use. But how do you apply your enthusiasm and basic knowledge? Specifically, what does a technical evaluator do?

In subsections III-B through III-E we try to tell you step by step what to do. But before we leap headlong into this pool of details, let us stand back and look from a distance. Let us see, in general, what direct cost analysis is all about before we get our feet wet.

THE THREE PHASES OF THE TECHNICAL EVALUATION

In section II and again in this section we talk, in turn, about direct material, direct engineering labor, direct manufacturing labor, and other direct costs. We have to discuss these cost categories separately. Each category, by definition, is different from the others Contractors usually use certain techniques for estimating each category s total cost. And you must look for certain key items when evaluating the estimate for each category.

None of this means that you should *completely* evaluate first the direct material estimate, next the direct engineering labor estimate, and so on. A technical evaluation consists of three major phases, during each of which you should give whatever attention is required to each direct cost category. If in any of the phases you feel that an estimate requires no further attention, you can put aside that estimate and concentrate on the others.

The three phases of the technical evaluation are the previsit phase, the onsite phase, and the postvisit phase (see figure III-A-1).

THE PREVISIT PHASE

A technical evaluation is no vacation. You have only a few days to pick through stacks of data, look through the plant and see what goes on there, exchange facts and opinion with contractor and Government

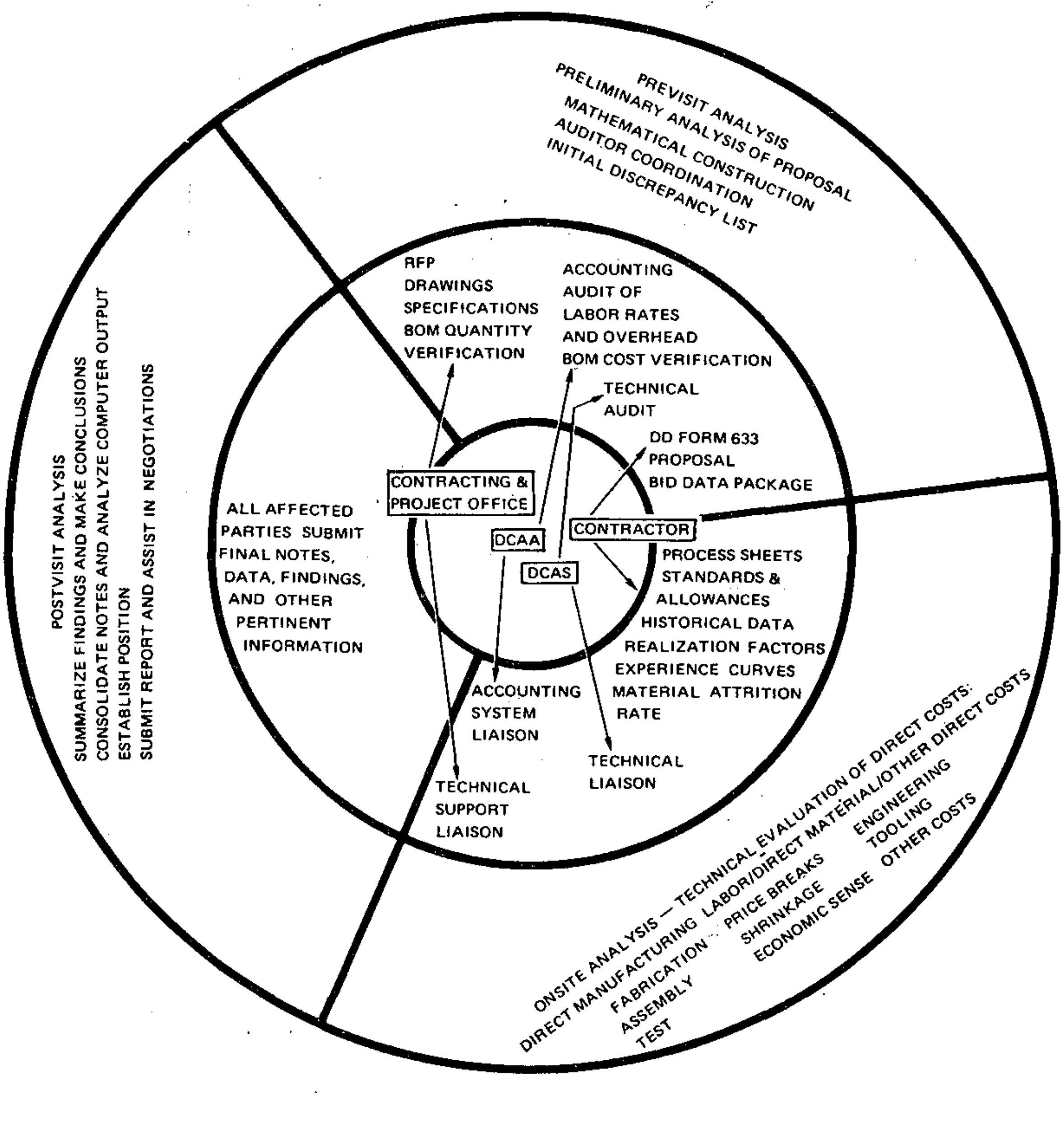


Figure III-A-1. The Three Phases of a Technical Evaluation personnel, and deliver your cost recommendations to the contracting officer. You must do a good job, too, because the Government pays for overestimates you overlook.

So plan to use your scarce time wisely. Develop a plan of action during the previsit phase of your evaluation, before you ever go to the contractor's plant. From the contractor's DD Form 633 identify the order of potential savings from the direct cost estimates. For example, suppose the proposed costs are $500,000 for direct manufacturing labor, $50,000 for direct engineering labor, $5,000 for direct material, and $50 for "other costs." What should you do?

You should plan to concentrate on the direct manufacturing labor estimate, because the $500,000 cost offers more potential for greater savings than the other costs offer. In each of the three phases, when you become satisfied with your efforts on direct manufacturing labor, you can go on to direct engineering labor, then, time permitting, to direct material. Note that if either the direct engineering labor cost or the direct material cost seems grossly overestimated, you should spend at least enough time on the affected category to determine an approximate fair cost. You should spend little time on the "other cost" estimate of $50, an insignificant portion of total contract cost.

ACCUMULATE AND EVALUATE DATA DURING THE PREVISIT PHASE.

In addition to the DD Form 633, you will be helped in your previsit phase by the contractor's proposal, all available DCAA and DCAS audit reports on the contractor, the design data package, and your coworkers' advice. In the previsit phase you should accumulate as much data about the contractor and his proposal as you can get.

Read the contractor's proposal. Find out how he estimates his costs. Add up all the estimated costs in the proposal, and compare the sum with the total of the direct costs listed on the DD Form 633.

If the two sums are not the same, either the contractor's math is wrong or he has failed to include in his proposal supporting data for his DD Form 633 estimates. Later, during the onsite phase, bring this to the contractor's attention, and request any absent information.

If the two sums are the same, you can assume the contractor correctly tallied his estimated costs in preparing both the basic proposal and the DD Form 633. Furthermore, there likely will be data of some sort with his proposal to back up each direct cost estimate. Your job now is to evaluate the backup data, to see if they reflect sound logic and efficient practices.

The contractor's supporting data may be statements and calculations within the basic proposal itself, or worksheets attached to the proposal. A typical proposal package would contain a basic, formal proposal document that includes descriptions of the estimating procedures used and the actual estimates. Attached to this basic proposal would be the worksheets on which he recorded information and figures estimates of individual cost items. But remember, a contractor can put his supporting data wherever in his proposal package he wishes, and his worksheets can be in whatever format he finds suitable. What is important is whether or not the data really show that the contractor's estimates represent fair and reasonable costs to the Government.

A contractor has the option of submitting a work breakdown structure (WBS) with his proposal, as described by MIL-STD-881. If he does, it will help you.

A WBS is a family-tree-type arrangement beginning with general descriptions of the overall work effort, then breaking the effort down by steps into smaller, more tightly defined work efforts (see figure III-A-2). The lowest level of work on a WBS is the "work package," which is a specific task to be performed by a specific worker or group (see figure III-A-3). A "cost account" is the lowest level of work for which the contractor accumulates cost records, and consists of one or several work packages.

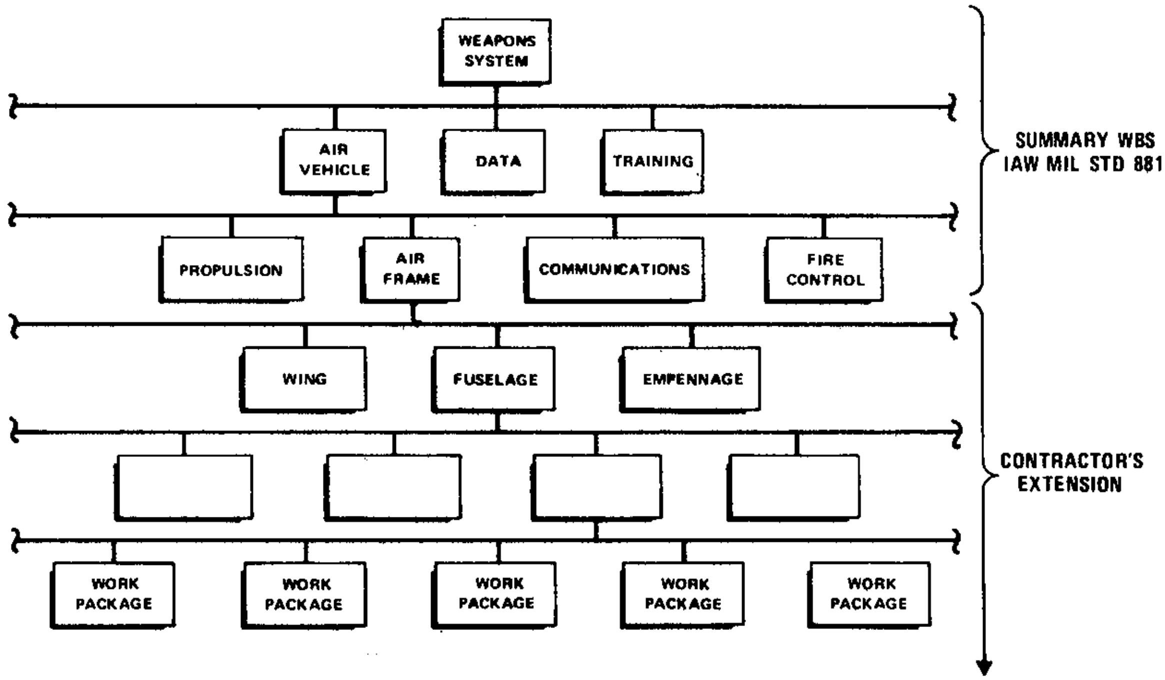


Figure III-A-2. Sample Work Breakdown Structure

The work effort included in a cost account can be anything from putting together an assembly to doing some simple procedure in a fabrication operation. As a rule, cost accounts should represent a group of tasks taking no longer than a year to perform. Efforts taking longer usually cannot be specifically defined or accurately measured.

Work packages normally account for about 90 percent of the work in the total WBS. The other 10 percent is accounted for by "levels of effort." Work put into levels of effort cannot be clearly defined, measured, and put into work packages assigned to individuals or groups. Engineering work would be in this category.

A contractor can assign work packages by using a chart that breaks down his labor force to form a matrix with his WBS. Such an arrangement is shown as figure III-A-4. Besides helping the contractor assign work, such an arrangement will enable you to see who does what.

Now look at the contractor's proposal package and identify all the items listed as direct costs. Some of these items, you may feel, are borderline items, which could have been classified as either direct or indirect costs. Moreover, based on your experience with similar Government contracts and perhaps with the particular contractor, you may know

WORK PACKAGE DESCRIPTION/JUSTIFICATION		
WP#: 4ACB AUTH: EAM	TASK TITLE: Develop Process Sheet SECTION#: 31622	 ISSUE#: 1

WORK PACKAGE TOTALS

SAL HRS	4.20	GRADE	S-6	DIRECT MAT	
HRLY HRS	0.75	GRADE	H-4	OTHER DIRECT	

TASK DESCRIPTION: Develop process sheets for manifold end caps, part numbers 9538261-1, -2.

Subtask 01: Prescribe fabrication operations

Subtask 02: Prescribe cosmetic finishing process

Subtask 03: Apply labor standards to operations

COST JUSTIFICATION:

Subtask 01: Task requires definition of appropriate method of fabrication by prescribing (ten) operations at 0.25 hour each, based on similar part number from prior contract. *Sal Hrs 2.50*

Subtask 02: Task requires definition of appropriate method of finishing by prescribing (three) operations at 0.15 hour each. *Sal Hrs 0.45*

Subtask 03: This task requires that each operation have applied to it a labor standard based on similar parts, standard data, or engineering judgment. These parts are judged to be moderately complex requiring 1.25 hours for this effort. *Sal Hrs 1.25*
Clerical labor to support this task is estimated at 0.75 hour. *Hrly Hrs 0.75.*

Figure III-A-3. Work Package Description/Justification

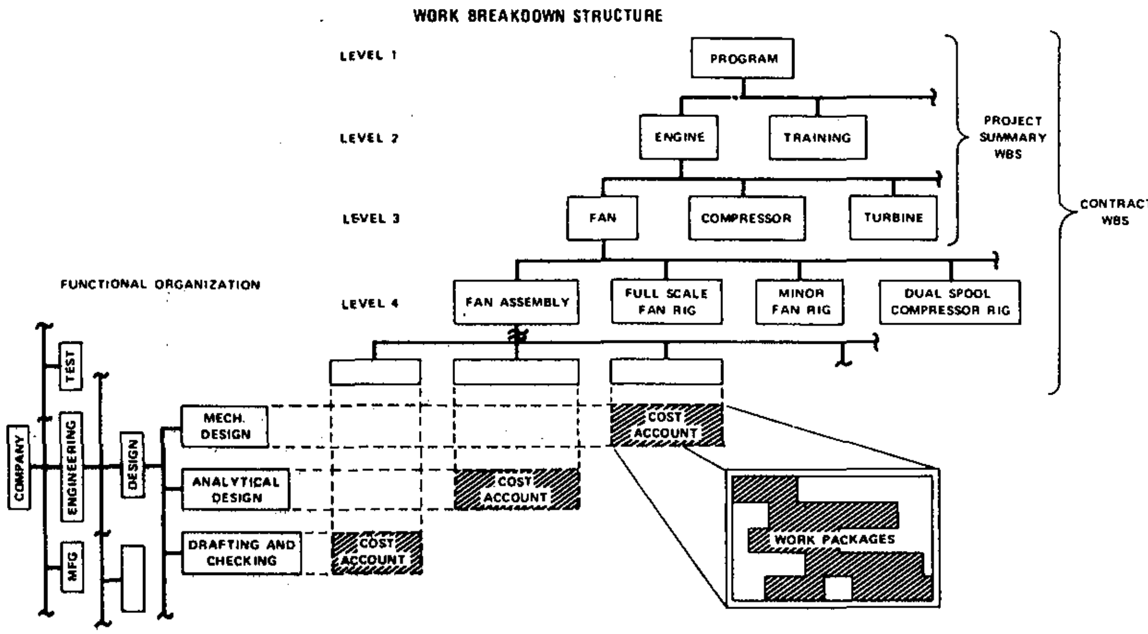


Figure III-A-4. Integration of WBS and Organizational Structure

that, in the past, some of the borderline items in fact have been considered indirect costs and charged to overhead. You must look for double-charges.

DCAA audits contractors' overhead rates, but in its audit reports it usually does not identify all the direct costs represented in the percentage rates. Instead, it will either approve or "challenge" the rates, recommend new percentages for the challenged rates, then leave it up to the contractor to adjust his rates. Later, at the negotiation table, the contractor must show the contracting officer that the rates are in line with DCAA's recommendations or explain why not.

This means that if double-charges are possible, and DCAA has not itemized the indirect costs represented in the overhead rates, you will have to call on DCAA. Even though its audit report does not list all costs charged to overhead, DCAA has reviewed and recorded the costs historically charged to overhead. You should get this information if you need it.

This does not mean the audit reports are of little value to you. In addition to overhead rates, DCAA audits cover cost-accounting procedures, material unit costs, and labor pay rates--all helpful information. If DCAA challenges the contractor's estimating procedures, it has isolated an area for you to evaluate. Material unit costs and labor pay rates interplay respectively with material quantities and labor hours, which you evaluate.

The design data package gives details about the end product to be built--its performance capabilities and, at some point, its physical characteristics. For new products, the Government project office may send with its solicitation a design data package giving only performance criteria. The contractor must develop the specifications and drawings describing size, shape, weight, and the other physical characteristics of the end product and all its components. As these specifications and drawings are developed, they are sent to the Government project office, which incorporates them into the design data package.

For products made before, the Government project office sends the contractor a complete design data package with its solicitation. Such a package contains all design specifications, drawings, and references to other specifications and drawings needed to construct the end product.

Try to get an up-to-date design data package from the Government project office. (You probably will not get one unless you ask for it.) From it you can judge approximately the product's complexity and the effort, material, and technology required to build it. You will be unable to do this alone. You will need help from engineers on the Government cost analysis team.

You also should discuss the contract in general with the other members of your team. Try to answer such questions as why was *this* contractor chosen for the contract, what prior experience does he have in making the particular end product, and what, if any, special assets permit him to produce the product more cheaply than other contractors could. You probably will find that the contracting officer picked the particular contractor because of some technical or cost advantage, but ask these general questions anyway. You may learn specifics about the contractor you can use in your onsite evaluation.

After you have completed your discussions with your Government teammates, add their opinions to the formal data you have accumulated from the contractor, DCAA and DCAS. Begin to isolate problems for which you will need to seek solutions during your onsite evaluation.

Throughout your previsit evaluation you should be listing the problems for which you plan additional research. Include all problems related to mathematical errors and inconsistencies, insufficient backup data and questionable existing data. List your questions for the contractor or some particular part of his organization.

In summary, during the previsit phase you should solve whatever problems can be solved by paperwork alone, isolate the problems that can be solved only by witnessing plant operations or by face-to-face talks with the contractor and his employees, and decide where in the plant you may be able to solve these problems. Do not consider this phase to be time lost from the onsite factfinding. It is your chance to plan your onsite efforts so that your time will be spent meaningfully.

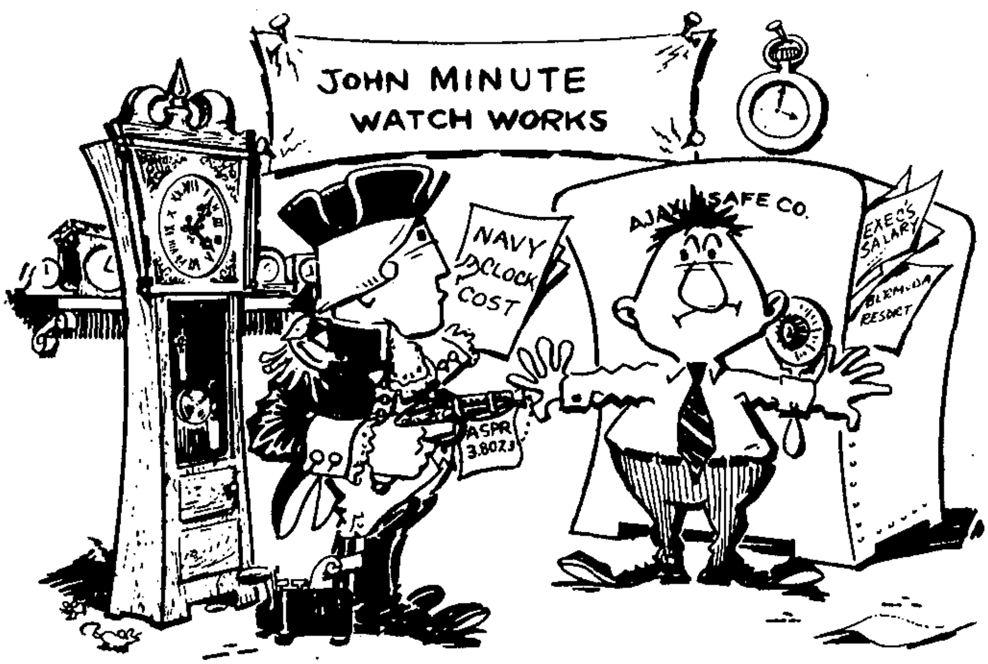
Now, having reviewed all available data, having secured counsel from your fellow Government specialists, having made your lists or problems and questions, having determined which cost categories offer the greatest potential for Government savings, and having given ample forethought to your onsite activities, you can visit the contractor.

THE ONSITE PHASE

Arrange to meet with DCAA and DCAS representatives when you arrive at the contractor's plant. They may be able to supply additional backup data unavailable to you previously.

Soon after this begin asking the contractor for any additional data you need for your evaluation. Rarely does a proposal package contain a complete, unquestionable description of every direct cost item. Some of the key documents that are not normally included in the proposal and that may help you are bills of material and documents that specify the contractor's labor standards program, his material allowance factors, and his prior contract performance.

When you ask for cost data, remember that Public Law 87-654 gives you the legal right to all cost data used by the contractor. ASPR 3-807-3 interprets this law to mean that a contractor must submit, and not merely



YOU HAVE THE RIGHT TO REQUEST AND INSPECT ALL COST DATA USED BY THE CONTRACTOR IN ARRIVING AT HIS PRICED PROPOSAL.

make available, to any authorized Government representatives all *requested* cost and pricing data for any contract valued in excess of $100,000 and awarded in the absence of adequate price competition. "Cost and pricing data" are defined in ASPR 3-807.3 as "...all facts which can reasonably be expected to contribute to sound estimates of future costs as well as to the validity of costs already incurred."

A contractor's submission of data is important, but ASPR 3-807.3 also adds that the data be "accurate, complete, and current." Cost data developed or accumulated within the last 2 years may be considered current. Older data are questionable unless they have been properly validated against recent comparable data.

You will have only a few days to spend in the plant, so you should get familiar with the plant as quickly as possible. The best way to do this is to arrange a plant tour. During the tour you should get to know the contractor's plant, where everything is, the general goings-on, and who is in charge of what. Afterward you can return to specific areas of the plant, and seek out answers to the questions evolving during the previsit phase and the tour.

You may find some answers by asking the contractor's production workers about machine capabilities and the amount of technical support necessary to maintain the equipment. Be polite; the responses will be better then if you are pushy or patronizing. Do not make a show of recording every word, but write down your important findings when you can be inconspicuous.

AT THE COMPLETION OF EACH DAY'S EVALUATION EFFORTS, YOU SHOULD ACCUMULATE YOUR NOTES AND ANALYZE YOUR FINDINGS.

Next will be a series of in-depth factfinding sessions with the contractor. You should now be familiar enough with the contractor's data, plant, manufacturing procedures, and estimating methods to ask him specific questions about possible overcharges. Ask him about any discrepancies between the Government's solicitation and his proposal, suspected mathematical inaccuracies, and anything else that may help you to evaluate his proposed costs.

During these sessions you should have pen in hand, vigorously taking notes on anything you feel is important. Besides helping you with your evaluation of the contractor's proposal, your notes should reveal any differences in what the contractor himself says about his manufacturing and cost-estimating techniques and what the contractor's representatives and production worker say.

Your methods in these sessions can range from a line-by-line challenge of the proposal and the DD Form 633 to a recalculation of some of the mathematical formulas the contractor used. At each day's end, probably in your motel room, you should accumulate your notes and analyze your findings.

The final act in the onsite evaluation is the exit interview. You and the other Government specialists have had time to evaluate your findings, although your findings may not yet be in terms of dollars and cents. You will talk in general terms with the contractor and his representatives about what you think is wrong with the proposal, about costs for which you wish to see additional substantiating information, and about how you think plant efficiency can be improved. Because the contractor's management is responsible for ensuring that the entire plant complies with your recommendations for improving efficiency, insist that a top management representative attend the exit interview.

Just because we call the last big happening in your onsite evaluation an "exit interview" does not mean that you shout a few words over your shoulder as you step out the plant door. You should allow enough time to discuss everything you wish to talk about. An exit interview can last from as little as an hour to as much as a full day.

THE POSTVISIT PHASE

Your postvisit evaluation is an evaluation of your previsit and onsite evaluations. Up to now you should have been recording everything you suspect could affect the contractor's estimates. During your postvisit evaluation, you should assess your findings, determine which of your findings really reveal contractor errors or inefficiences, and organize your findings into a document package the contracting officer can use in the formal negotiations.

Probably the notes taken during your evaluations will not be pretty, many of them having been hastily scribbled. The postvisit phase is your chance to tidy up.

Also, many of your findings would have been noted on terms of material quantities or labor hours. These notes have to be translated into dollars-and-cents terms, because the formal negotiations will be of the direct costs as specified on the contractor's proposal.

You can use whatever worksheets you wish to figure your estimates of reasonable direct costs. But when you finish, your findings should be put into a format that corresponds with the order in which costs are presented in the contractor's proposal. During the negotiations, when-

DURING THE POSTVISIT PHASE, ORGANIZE YOUR DOCUMENT PACKAGE TO GIVE TO THE CONTRACTING OFFICER.

ever a particular cost category is up for review, the contracting officer should not have to spend time searching through his paperwork to find the data supporting the Government position. You can include notes and worksheets with the formal documents, but the notes and worksheets should be references to the part of the proposal to which they pertain.

Finally, having itemized your findings to correspond with the order of the proposal, and having arranged your supporting paperwork in a legible form properly referenced to the applicable parts of the proposal, you can work toward your direct cost recommendations.

DATA SOURCES

Where do you find data with which to verify a contractor's proposal? As you gain experience, you will learn about the types of support data and where to find them. You will develop the key asset of being able to ask the right contractor department head for the right information.

Tables III-A-1 and III-A-2 show data sources and data items typically used by cost analysts. Ideally, you could find enough support information in the proposal package to eliminate the need for a personal onsite review. (This ideal seldom, if ever, occurs.)

Some of this information gives physical descriptions of the product, the contractor's work force, and his facilities. Other data describe the efforts, time, and money required to produce the product. A knowledge of the first type of data will enable you to evaluate the second. For example, knowing the contractor has several numerically controlled machine centers, you can accept more technical support hours than you would otherwise.

Table III-A-1. Data Items and Their Sources

Data description	Data source
Engineering drawings	Design data package
Product specifications	Design data package
Written description of product	Proposal
Bills of materials	Manufacturing engineering, purchasing dept
Organization chart	Personnel dept
Ratios of labor, support, and engineering organization	Personnel dept
Job descriptions and skill-level breakdown	Wage and salary administration
Collective bargaining contract	Labor relations dept
Definition of direct/indirect labor categories	DCAA audit, production management, wage administration
Description of plant facilities	
Special equipment and processes	Proposal, process engineering
Management information system and ADP capability	ADP management
Manufacturing capability	DCAS capability study, prior contracts
Process sheets	Industrial and manufacturing engineering depts
Make-or-buy program	Proposal
Production schedules	Solicitation, proposal, production scheduling dept
Purchase orders	Purchasing dept
Material allowances:	
Estimates	Proposal, bills of material
Actual	Production records of start quantity less shipped quantity
Proratables	Proposal support data
Cost-Estimating procedure	Proposal, cost-estimating dept
Production output records	Accounting department, production control department, management information system

Table III-A-1. Data Items and Their Sources *(Continued)*

Data description	Data source
Rework allowance	Proposal support data, inspection records, quality control dept, production management
Schedule backlog	Production scheduling dept, management information system
Labor efficiency report	Production management, industrial engineering dept
Variance from standard performance	Cost-accounting dept, industrial engineering dept
Breakdown of raw material dispersals	Inventory control dept, raw material stores
Estimated spread sheets	Proposal support data
Departmental estimates	Respective department management
Experience curve derivations	Cost-estimating dept, industrial engineering dept
Cost-estimating worksheets	Cost-estimating dept, industrial engineering dept
Work measurement standards	Industrial engineering
Subcontractor quotes	Proposal, make-or-buy program, purchasing dept
Historical costs:	
Estimated and actual spread sheets	Contracting officer, direct cost analysis files
Direct cost factors	Prior contracts in contracting officer's files, contractor ADP files
Independent audits	DCAA, private consultants, NAVPRO, AFPRO, DCAS

Table III-A-2. Data Sources and Data Items

Data sources	Data items
Manufacturing engineering files	Process sheets
	Manufacturing process capabilities
	Engineering drawings
	Bills of material
	Tooling requirements

Table III-A-2. Data Sources and Data Items *(Continued)*

Data sources	Data items

Design engineering files	Product specifications
	  Reliability
	  Quality
	  Functionality
	Engineering drawings
	Special requirements
	  Temperature
	  Handling

Management information systems	Summary production reports
	  Inventory
	  Output
	  Schedules
	  Labor efficiency

Production control	Production schedules Production output records Material allowances and accounting procedures Bills of material for current jobs Material storage and dispersal procedures

Industrial engineering files	Development of cost-estimating techniques
	  Predetermined time values
	  Standard data
	  Worksheets
	  Work-sampling studies
	  Experience curves
	Process sheets
	Historical labor performance data
	Job descriptions and skill breakdowns
	Description of plant facilities and capabilities

Cost-estimating dept files	Cost-estimating and accumulating procedure Departmental manpower requirements Product material estimates Experience curve applications Labor performance factors

Quality assurance files	Inspection plans and procedures
	  Rework history
	  Unusual product specifications

Table III-A-2. Data Sources and Data Items *(Continued)*

Data sources	Data items

Purchasing dept files	Current purchasing policy
	  Purchase orders
	  List of vendors
	  Quotes from subcontractors
	Historical purchasing policy
	Make-or-buy program

Personnel dept	Relative labor mix, amount, and quality Ratios of various labor groups Organization characteristics Names of key personnel and contractor organization terminology

Production management files	Labor performance reports
	Definitions of labor categories
	  Direct/indirect
	  Skilled/unskilled

Top Management	Explanation of questionable policies Authority for capital expenditures Knowledge for other data sources
Accounting dept files	Cost breakdowns of labor category versus major product assembly Differentiation between direct and indirect costs Breakdown of overhead items Actual cost data (historical)

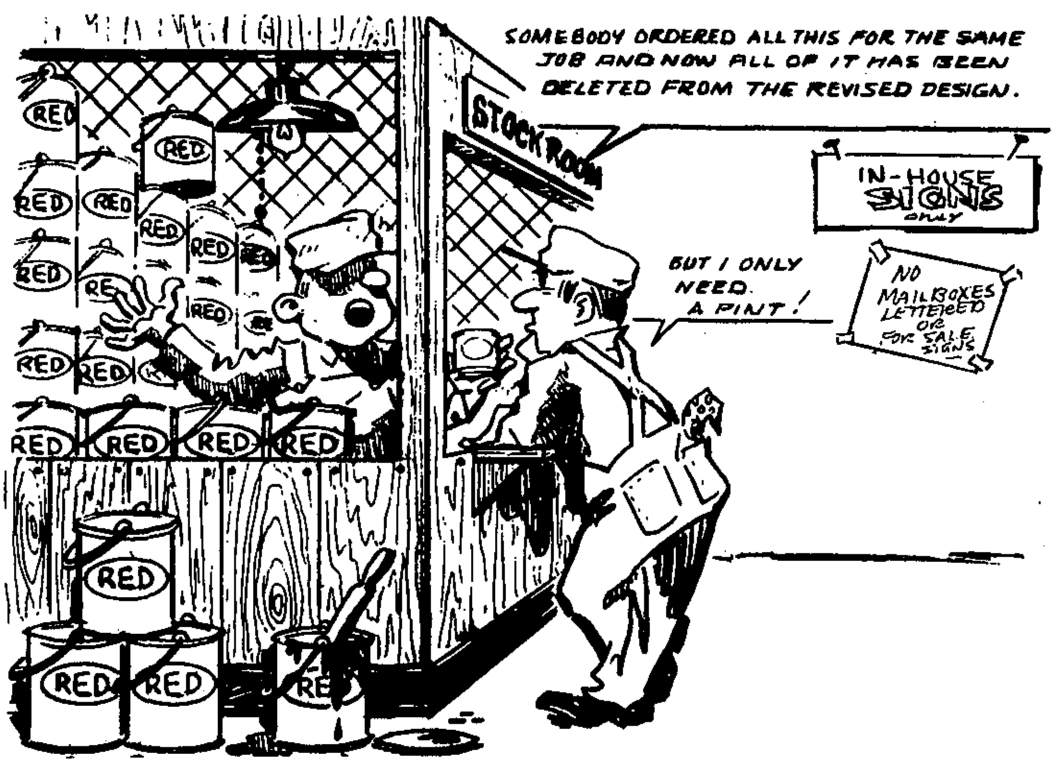
Subsection III-B. EVALUATING DIRECT MATERIAL ESTIMATES

Imagine a Government contract calling for hardware production, with a military standard specifying enameled steel for the particular type of hardware. The contractor's purchasing department, wishing to ensure the enamel arrives in time to avoid production delays, orders fifty 1-gallon cans of enamel before production begins. Then the Government requests that production be "put on hold." The enamel arrives.

When the "hold" is lifted the Government says it wants anodized aluminum rather than enameled steel, its own standard notwithstanding. The enamel is of no use for the contract.

Who pays?

The Government's "change in direction" would mean that it should pay for the enamel--but not necessarily what the contractor paid. The con-



tractor likely was inefficient in buying 1-gallon cans. A 10-gallon can of enamel usually costs less than ten 1-gallon cans, so probably buying five 10-gallon cans would have been more economical than buying fifty 1-gallon cans. If so, the technical evaluator should recommend a cost reduction.

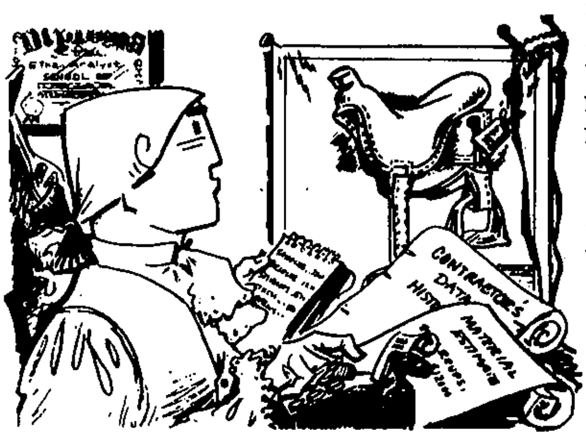
Our example shows how a technical evaluator could save the Government money by spotting a contractor inefficiency in buying direct material. Contractor inefficiencies in either buying or using material can be costly. How can *you* spot them?

THE PREVISIT PHASE OF YOUR DIRECT MATERIAL EVALUATION

In the previsit phase you should get as much paperwork about the direct material estimates as you can get. It is possible, although unlikely, that in this phase you can gather enough valid data to support the contractor's estimates or to pinpoint deficiencies in them.

You should have the Government's solicitation (RFP or RFQ) and the contractor's proposal package. Compare them. Is the contractor promising to deliver what the Government asked for? Is the material the contractor plans to buy really needed to build what the Government wants? Government project office engineers can help you answer these questions.

DCAA's audit report will be a great aid to you. Although it does not tell everything about the contractor's estimates, it can tell you such things as how much of the cost estimate is based directly on quotes from outside vendors and how much has been estimated by some other technique, the contractor's waste and obsolescence factors, any shrinkage factors proposed by outside vendors, purchase and production lot sizes, and the contractor's methods for allocating indirect material costs.



THE CONTRACTOR'S PROPOSAL DATA SHOULD SUPPORT HIS MATERIAL ESTIMATE.

During this phase you may try to validate the contractor's estimates by calculating some ratios, if sufficient data are available. If the contractor has produced identical equipment before, find out the actual costs he incurred. Then calculate the ratio of his direct material cost to his direct labor cost. Next, calculate the same ratio from the direct material and labor estimates in the proposal. Compare the ratios.

If the ratios are close, you may decide to accept his direct material estimates without further analysis, provided that you feel that the actual costs incurred by the contractor were reasonable. To save yourself from going into cost analyses of prior contracts, calculate ratios from as many prior contracts as you have time, and take the average. Some ratios will be available in industry publications.

If the contractor has not made the same equipment before, you can still check out his raw material estimates by calculating ratios. Whenever the contractor is using raw material he has used before in the same way, you can use ratios from his past work for comparison with his raw material estimates. Some of the ratios you could calculate are:

- End products produced to raw material used
- Raw material used to direct labor hours expended using it
- Raw material cost to either direct labor hours or direct labor cost

What if your past and present ratios differ significantly? Well, if you consider the past ratios about right, you can make gross estimates of what the current contract's material requirements should be. Just apply the ratios of the past contracts to the current proposal.

For illustration there is the procedure many contractors use to estimate raw material costs in their sheet metal shops. Each accounting period these contractors calculate (1) the total labor hours expended in the shop and (2) the total cost of raw material used in the shop. Then they figure the ratio of labor hours to raw material costs for the accounting period. This ratio can be used in future contracts either for estimating labor hours when raw material costs are known or for estimating raw material costs when labor hours are known. DCAA audits such ratios when contractors use them for cost-estimating. To keep them reliable, contractors should review them each accounting period.

The principle is that ratios should hold constant over time. Whenever they differ from their historical relationships, one of the estimates probably is overstated. If the historical ratio of labor to raw material is 1 to 1, all new estimates for like products should be adjusted until their ratio is about 1 to 1.

Even if prior data are inadequate for making your comparisons, calculate ratios for the proposed contract anyway. You can use them later when evaluating similar contracts.

THE ONSITE PHASE OF YOUR DIRECT MATERIAL EVALUATION

In few previsit phases will you find enough data to back up the contractor's direct material estimate in full. In most direct cost analyses you must get additional information from contractor personnel and investigate the contractor's material purchase and usage practices *while in his plant.*

THE PLANT TOUR

Your initial plant tour should take you along the "material flow routes," which include the plant areas where material enters the plant, is handled, and leaves the plant. These areas include the receiving, storing, dispensing, fabrication, assembly, inspecting, and shipping departments.

Take your note pad along on your tour. As you witness inefficiencies, document them. And as you gain experience, you may be able to estimate the contractor's shrinkage during such tour. With your rough estimates, coupled with your notes on plant efficiency, you can begin to assess whether or not the contractor's proposed factors are reasonable.

Also during your tour you should observe the degree of automation and relate the contractor's current capabilities with those he may have had for any previous Government buy. Automation affects both labor time requirements and shrinkage factors, and a switch from a manual to an automatic operation makes use of historical data dubious. If you determine the contractor's data are outdated, you must rely on your personal experience and published industry data to evaluate his material allowances.

THE PURCHASING DEPARTMENT

Either during your plant tour or on your subsequent return to the plant for an in-depth analysis, you should get to know the purchasing department. This department is responsible for material unit prices, purchase lot sizes, material deliveries, receipt of material, and expediting material on to production. It produces priced bills of material and keeps material cost, receipt, and delivery records.

THE MATERIAL PLANNING AND COORDINATING DEPARTMENT

You also should get acquainted with the group charged with overseeing material's flow through the plant. This group reviews material purchases, establishes purchase and production lot sizes, sees to it that the proper material is available at the right place when it is needed, estimates shrinkage, and is the focal point for the information on which the contractor's direct material estimates are based. A common name for this group is the material planning and coordinating department.

As soon as you have time, ask this group some questions. What shrinkage factors are applied? How are they applied? Can data support these factors? What kinds of documents were used to record historical scrap, spoilage, and obsolescence rates? Was there competition among outside suppliers to achieve minimum costs? What evidence can be supplied to support the contractor's production and purchase lot sizes? Was a material experience curve used? If so, is it documented?

Figure III-B-1 is a list of documents containing data needed by the material planning and coordinating department to plan the purchase and use of direct materials. Facsimiles of typical report documents that back up the contractor's proposed material factors are shown in figures III-B-2, III-B-3, III-B-4, and III-B-5. Note that the format used for the contractor's material documents is immaterial, so long as the reports are up-to-date, accurate, and available. Remember, also, these documents are historical documents; they tell only what did happen in the contractor's plant and not what should have happened.

Sometimes this group can answer all your questions about the contractor's direct material estimates. Other times it cannot. And some contractors do not have such a group.

When contractor personnel cannot satisfy you that the contractor's estimates are what they should be, and material costs are significant, you should take a closer look at the contractor's estimates. To do this you will need the same data that would be used by a material planning and coordinating department and listed in figure III-B-1. The most useful document is the bill of material.

SELECTING ITEMS FROM THE BILLS OF MATERIALS

You will not have time to evaluate every contractor estimate. To cross-check the contractor's estimates, you must select a few items to evaluate. Then, if the same inefficiencies keep crawling in, you must assume they prevail in all the contractor's estimates. If you find, for example, that poor purchase planning has elevated the costs for your selected items, not only should you ask for cost reductions for those items, you also should ask the contractor to show why all of his material estimates should not be reduced.

A priced master bill of material shows a breakdown of the complete end product and can be used as a guide to high-cost assemblies. You should select high-cost assemblies for analysis because finding an inefficiency in them ensures the Government of greater savings than finding the same inefficiency in inexpensive assemblies. Although you can generalize your findings, it is better to have documented evidence on items offering the greatest potential for cost savings.

After you have selected some high-cost assemblies, get the bills of material for those assemblies, which you should select because you will be evaluating lot sizes. These items give you a better chance to see if the contractor is taking full advantage of price breaks.

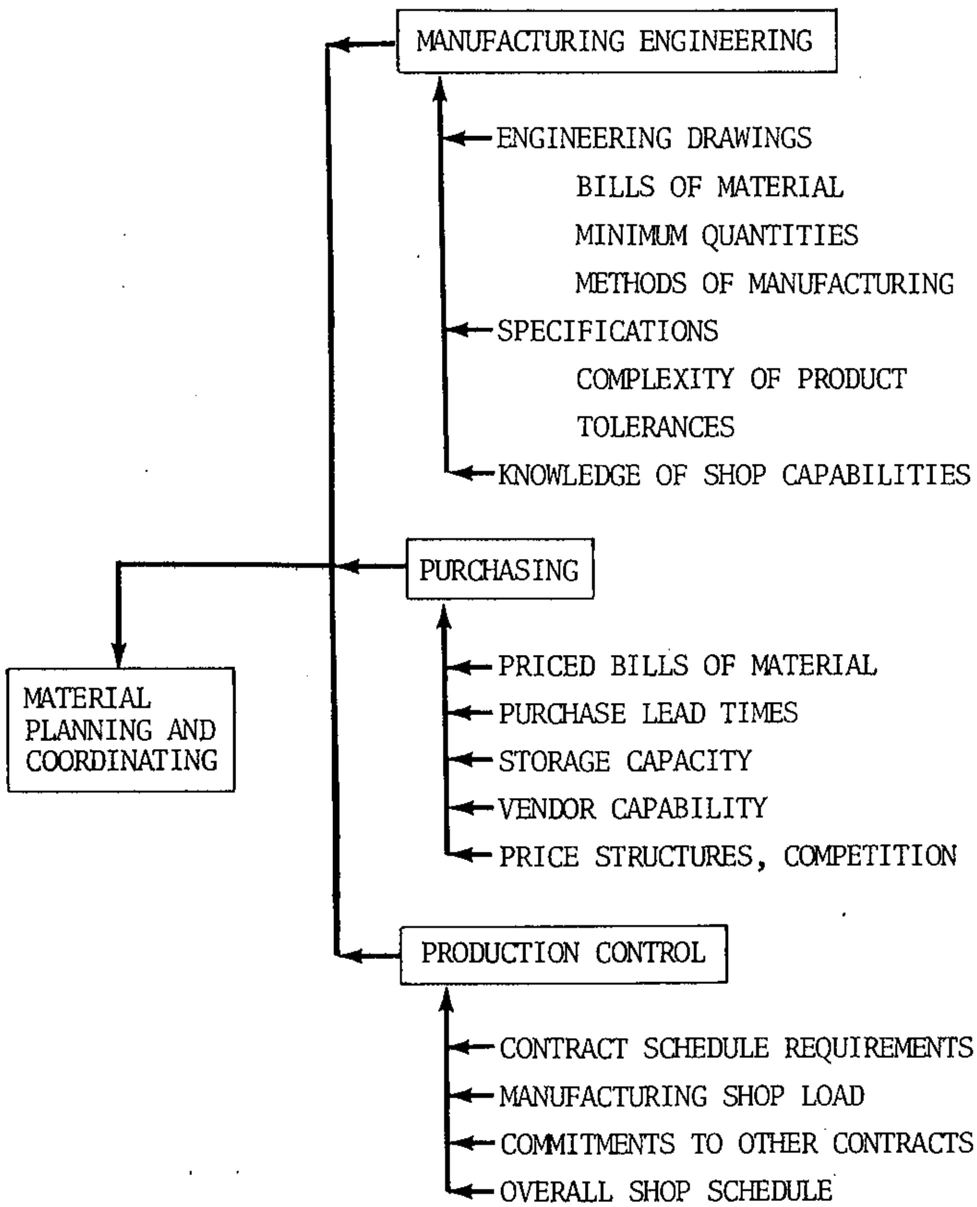


Figure III-B-1. Direct Material Data

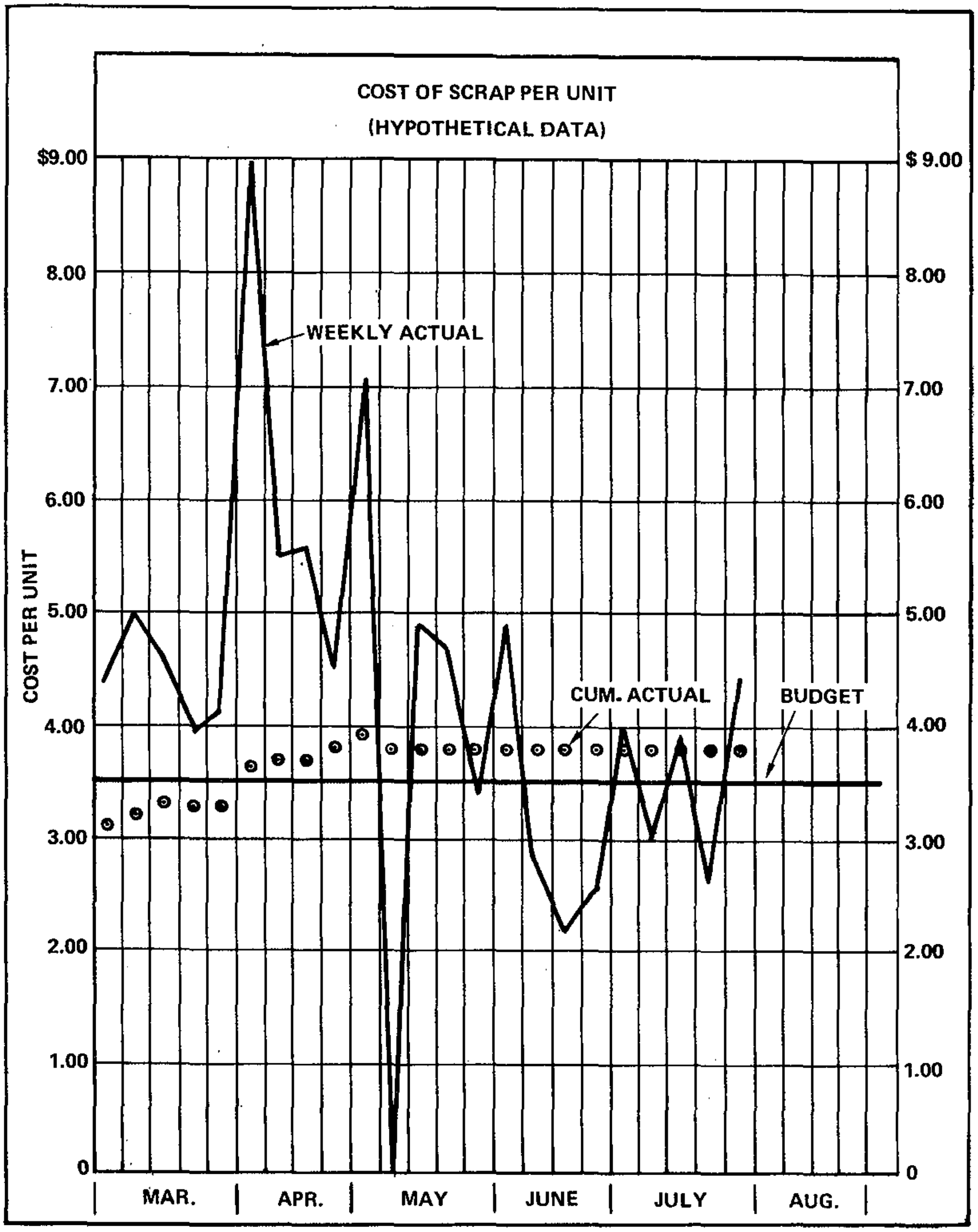


Figure III-B-2. Scrap Analysis Reflecting Trend of Variance from Allowed Cost of Scrap per Unit of Production

Description		No. of Pieces				
Part No.	Name	Produc-tion	Scrap	Percent Scrapped	Cost	Reason
647C	Hinge	12,320	207	1.68	$ 8.28	
871R	Ring	8,620	73	.85	3.65	
1122	Flap	3,110	672	2.16	282.21	Defective die
1816	Support	8,520	40	.47	16.00	
1871	Spoon	11,890	90	.76	1.80	
2167	Ruler	1,245	--	--	--	
2173	Cap "R"	14,505	1,070	7.38	$107.00	Substitute material
2271	Cap "T"	8,140	72	.88	23.60	
	Total				$ 440.57	
	Cost of Scrap--Year to Date				$18,497.12	

Figure III-B-3. Summary Scrap Report

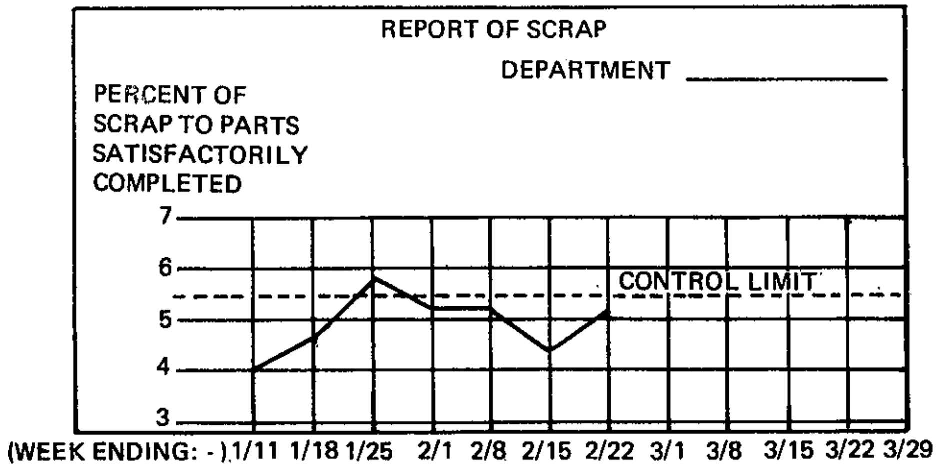


Figure III-B-4. Graphic Scrap Report

DEFECTIVE WORK REPORT

DATE ______________ NO. ______________

DEPARTMENT RESPONSIBLE ________ STANDING ORDER NO. ________

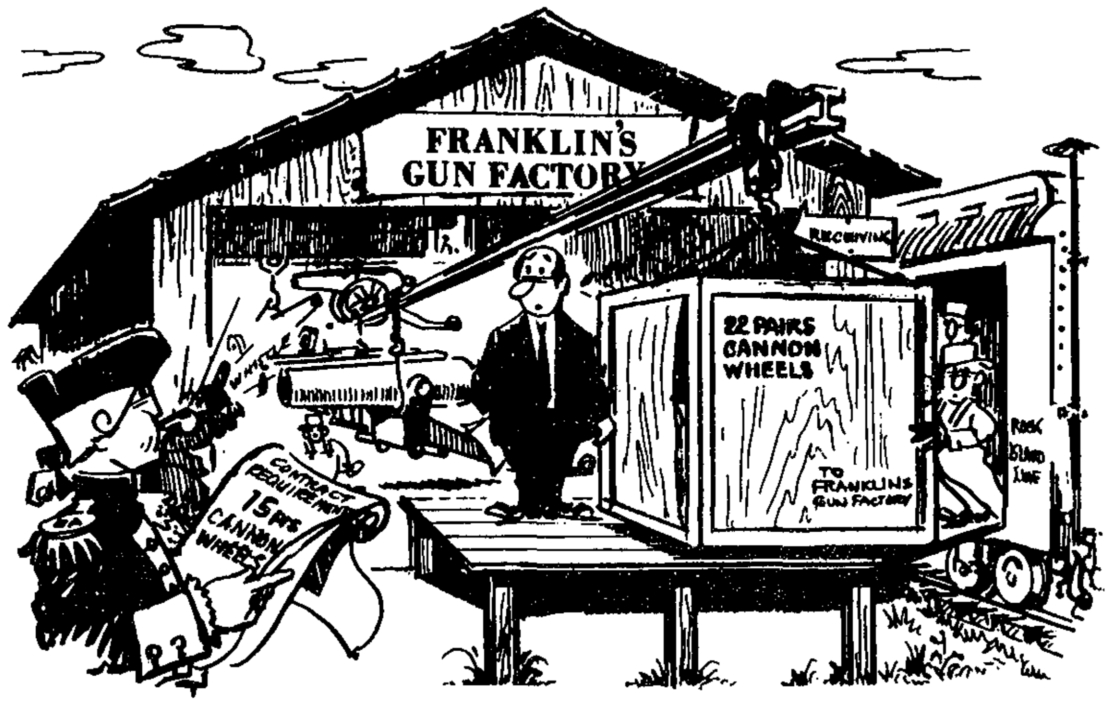
NATURE OF DEFECTS ______________

CAUSE OF DEFECTS ______________

DESCRIPTION OF WORK TO BE DONE	DEPT NO.	COSTS INCURRED				
		MATERIAL	LABOR		MFG. EXPENSE	TOTAL COST
			HOURS	COST		

SIGNED:

Figure III-B-5. Report on Unsatisfactory Work



COMPARE BILL OF MATERIAL REQUIREMENTS FOR HIGH-COST ITEMS WITH QUANTITIES PURCHASED IN ORDER TO CHALLENGE SPECIFIC CASES OF EXCESS PROCUREMENT.

EVALUATING SHRINKAGE FACTORS

The DCAA audit report will contain an assessment of the contractor's shrinkage factors for various materials and operations. But remember, DCAA performs audits periodically--and not necessarily at the time any particular proposal evaluation takes place. The shrinkage factors DCAA evaluates are those the contractor actually incurred in past work. The audit considers whether or not the contractor's historical shrinkage factors are reasonable enough for estimating the overage in future work.

This means that DCAA probably does not take into account the quantities required for the proposed contract. As production runs grow larger, shrinkage rates should diminish. When contracts have large material requirements, larger production runs can be planned for, meaning fewer setups and less shrinkage.

DCAA's audit, then, considers only past quantities. If the proposed contract calls for material quantities significantly larger or smaller than the quantities dealt with in the past, *you* will have to see that this is reflected in the contractor's proposed shrinkage.

DCAA analyzes shrinkage factors by comparing them with shrinkage factors found to be average for the industry. Many average shrinkage factors for particular material items and operations can be found in industrial journals and manuals (see the bibliography).

Sometimes contractors must work with material they have never worked with before, in which case there will be no actually incurred shrinkage for DCAA to evaluate. Whether or not this is true, you should check the proposed shrinkage factors for the high-quantity items you selected from assemblies' bills of material. But if a high-quantity item is not covered in the DCAA audit, you should analyze the proposed shrinkage rate for that item with especial thoroughness. If the contractor has not based shrinkage on his own history, you should find the basis for his estimated shrinkage.

How do *you* analyze shrinkage factors?

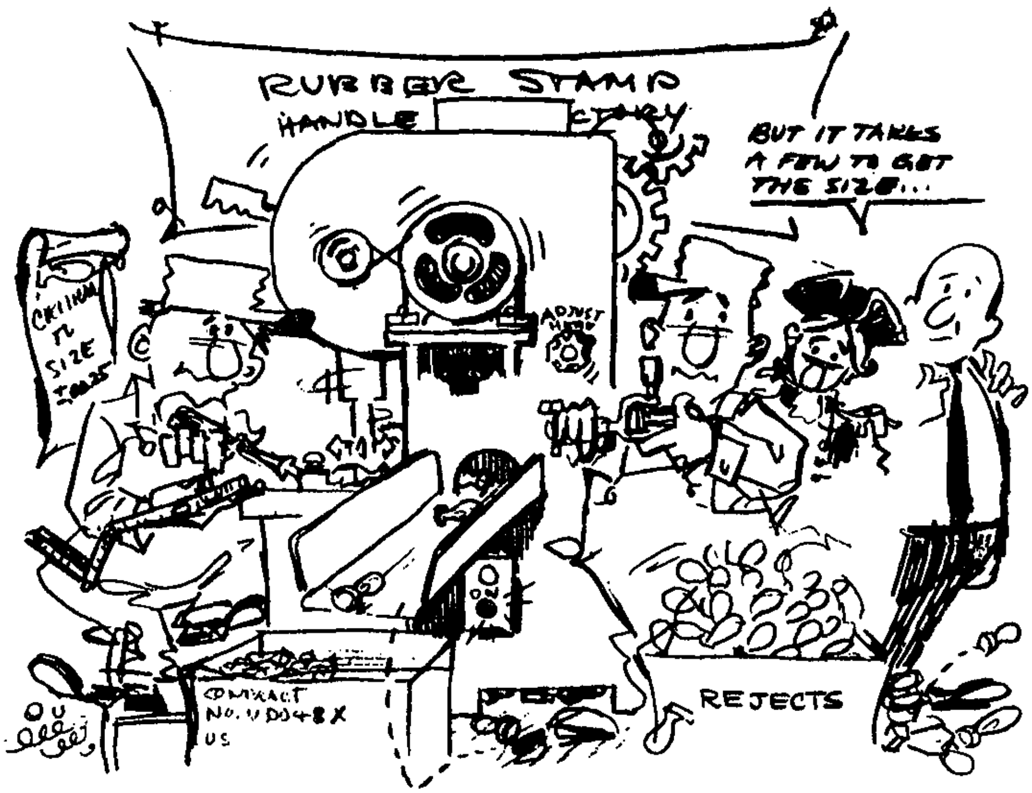
You do it about as DCAA does it. You compare proposed shrinkage factors with industrial averages for the same or similar items. If the contractor has quoted no shrinkage percentages in his proposal, you can find them out yourself by studying bills of material for items already purchased. Listed on such bills will be the numbers of items required and the numbers of items purchased, and by subtracting required items from purchased items you can tell the shrinkage the contractor has anticipated.

You should look for consistency in the contractor's application of shrinkage factors for identical items. If inconsistencies in the bills of material suggest that the allowed-for shrinkage is based not on calculated factors but on arbitrary guesses, question the contractor.

When satisfied with the contractor's consistency, go ahead with your comparisons. Are the contractor's proposed shrinkage rates in line with the averages for the industry? If they are not, ask the contractor about them.

The contractor may have some good reasons why his factors are out of line with industrial averages. For this reason, you should talk with Government engineers knowledgeable about shrinkage and the effects on shrinkage caused by manufacturing conditions, product characteristics, and lot sizes. Then look at how the contractor historically has controlled shrinkage, to see if his shrinkage rates differed with industry's in prior similar contracts. This information will be available in such documents as listed in figure III-B-1, which the contractor used to record actual shrinkage in prior contracts.

If the contractor has not differed with industry in the past but is differing now, find out why. Again, you will need help from project office engineers--this time to study possible changes in manufacturing conditions necessitating the altered shrinkage rates.



EVENTUALLY THE GOVERNMENT AND BIDDER MUST AGREE ON AN ALLOWABLE RATE OF SHRINKAGE. YOU MUST CHECK ON INEFFICIENCIES INFLUENCING THE FACTOR USED.

You will need help from your engineering teammates when you work toward the Government's position on the proposed factors. If some factors are found satisfactory and others are not, record those found unsatisfactory and ask the contractor about them when you have the chance.

Finally, check with DCAA about the contractor's resale of scrap during the previous year. Selling scrap may allow the contractor to recover a substantial portion of his scrap losses.

EVALUATING EXPERIENCE CURVES

See appendix B.

EVALUATING CONTRACTOR DECISIONS THAT
AFFECT MATERIAL UNIT COSTS

Make-or-Buy Decisions

You should ensure that the contractor has submitted a make-or-buy program, if one was required. Get a copy of the program, and try to answer the following questions:

YOU SHOULD CHALLENGE THE COST OF IN-HOUSE FABRICATION OF AN ITEM THAT THE CONTRACTOR CAN BUY FROM ANOTHER SOURCE AT A LOWER PRICE IN THE REQUIRED QUALITY AND QUANTITY.

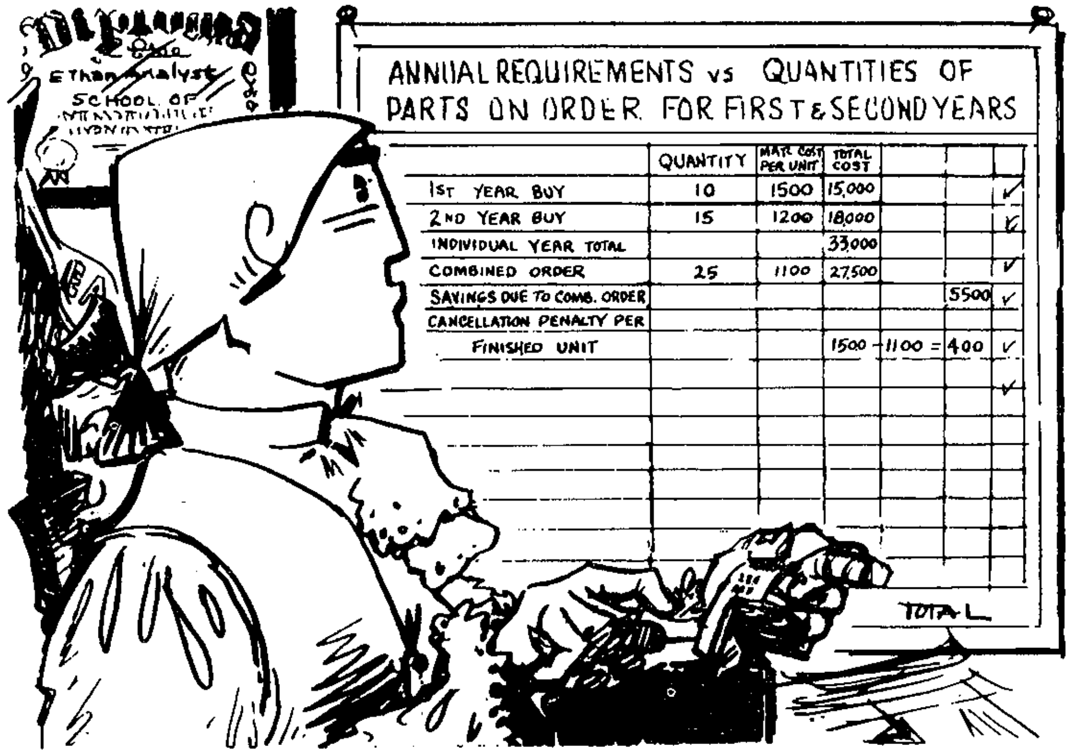
- Is the contractor's list of make and buy items complete?
- Overall, are his recommendations based on sound logic?
- Do you agree with all of his recommendations?
- Which, if any, do you disagree with? Why?

Purchase and Production Lot Size Decisions

After selecting some high-quantity items, ask the contractor's purchasing department for purchase orders for those items. From them you can determine how many items were bought, the quantity per order, and any price breaks. You also should try to get a list of other contracts that will require identical items so that the possibility of combined purchases can be examined. Buying at one time for more than one contract increases the likelihood of price breaks. (See appendix B, page B-24, for how to calculate economical lot sizes.)

Multiyear-Buy Decisions

Ask Government contract administration personnel about the length of the proposed contract, the conditions set by cancellation clauses, contract options, and any information the contractor might have about future buys of the same end product. The timing of material purchases and multiyear funding are critical. You must know them.



LEARN THE TIMING OF MATERIAL PURCHASES AND MULTIYEAR FUNDING

Purchased Parts, Subcontracted Items, and Shrinkage

Examine the proposal and bill of material to ensure the contractor is buying purchased parts and subcontracted items in the quantity actually needed for the end product. He should allow for no shrinkage in buying these items, for they are fabricated by an outside vendor who should guarantee his work. He should replace defective items at no cost to the contractor or Government.

Raw Material--How Much?

Contractors have to allow for some shrinkage when buying raw material, and you should evaluate their proposed factors as previously described in this subsection. Also, you should evaluate their purchase lot sizes.

Standard Commercial Items

If a bill of material contains standard commercial items, make sure the costs meet the guidelines presented in ASPR 3-807.1. ASPR3-807.1 stipulates that the cost for a standard commercial item be *an established catalog or market price of a commercial item sold in substantial quantities to the general public.*

You will not have to analyze these items' costs if they are sold to the general public in substantial quantities at costs consistent with the costs charged to the Government. The contractor should have a catalog listing their prices, which will allow you to compare costs.

Interdivisional Transfers: At Cost or Other than Cost?

Interdivisional transfers at cost is the rule; at other than cost the exception. Whenever an interdivisional transfer is charged to the Government, you should find out if the cost quoted by the contractor includes profit or fee for the originating division. If so, make sure that one of the two following conditions is met:

- The price is the established catalog or market price of a standard commercial item sold in substantial quantities to the general public.

- The price was favorable under adequate price competition.

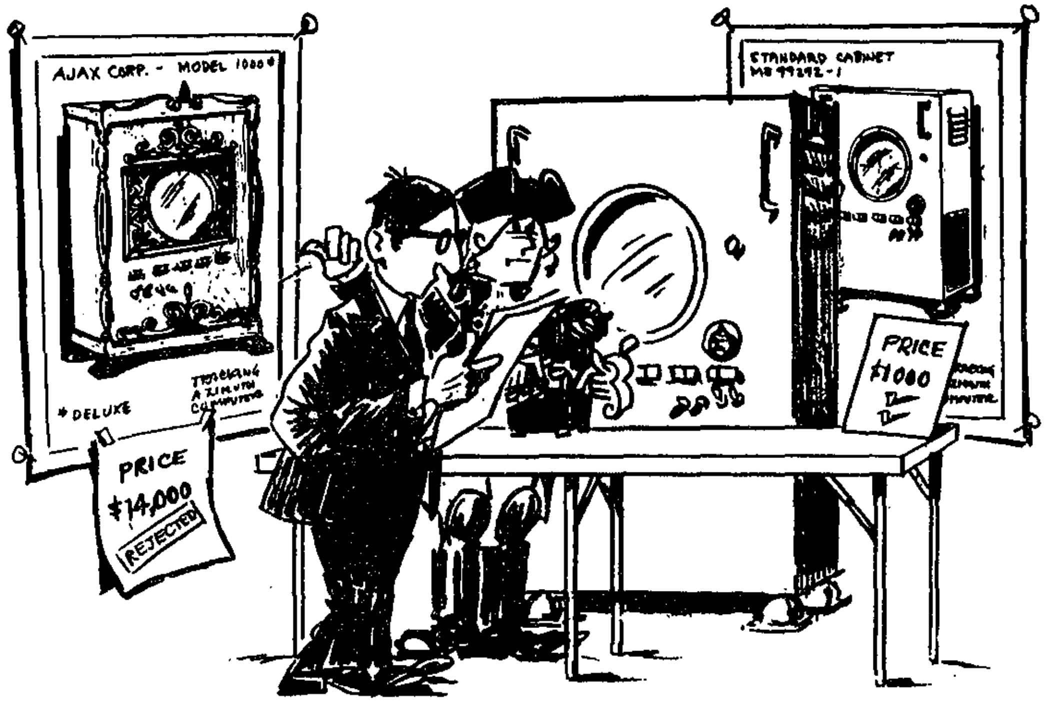
You also should ensure that under neither condition does the price exceed the originating division's price to his most favored customer.

For interdivisional transfers at either cost or cost plus profit, if the originating and contracting divisions use common overhead and G&A accounts. If they do, make sure that the Government has not been double-charged for these elements--once in the bills of material, then again on the DD Form 633.

Standard versus Nonstandard Parts

Bills of material should point out which parts are nonstandard. By studying contractor data and getting help from project office engineers, you should see whether use of nonstandard parts is really necessary and, if so, whether their proposed costs are reasonable.

An analysis of proposed nonstandard parts can save the Government considerable amounts of money. For example, one contractor proposed a nonstandard cabinet designed to withstand the MIL-S-901 high-impact shock test. Thirty such cabinets were to be constructed, costing the Government $14,000 each. Government cost analysts, however, recommended that the contractor purchase a standard commercial cabinets at $900 each, then install shock mounts at a cost of $100 for each cabinet. This recommendation enabled the contractor to comply with MIL-S-901's design requirements, and it enabled the Government to save $390,000 in direct material costs.



SEE IF CHEAPER STANDARD PARTS CAN BE SUBSTITUTED FOR EXPENSIVE NONSTANDARD PARTS.

Spare Parts and Continual Obsolescence

Most of your efforts will take place before production begins. Nevertheless, you should watch for items you feel are highly subject to design changes during production. Few technical evaluators are qualified design engineers, so most likely you will have to work with project office engineers to verify or remove your suspicions. If you find an item is highly subject to design changes, remind project office engineers to examine each proposed change to see if any additional expense is justifiable by product improvements.

With some design changes, the item becomes harder to make. This means that repeated obsolescence can enable a contractor to capture the spare parts business. By claiming sole capability of manufacturing an item, the contractor can win the business for himself, thus eliminating price competition. This is undesirable to the Government and, again, you should remind project office engineers to safeguard the Government's interests.

Finally, you should remind project office engineers to watch the contractor's purchase lot sizes if he does win the spare parts business. Material for both the original hardware and the spare parts should be bought at the same time if possible.

EVALUATING INDIRECT MATERIAL COSTS

Evaluating overhead accounts is a DCAA function, but you should be familiar with them to prevent double-charges. You should look for material costs that normally are found in plantwide overhead or special proratable rates but that have been charged as a direct cost. Furthermore, you should identify which material costs are in plantwide overhead rates and which are in special proratable account rates, and question any material cost charged to both.

No matter how a contractor calculates overhead, you should be able to recognize a reasonable overhead rate. The range of fair percentages can be determined by your experience with other overhead rates or by reference to published industry data. The contractor should be able to provide historical support for all overhead rates and, of course, to explain high rates.

THE POSTVISIT PHASE OF YOUR DIRECT MATERIAL EVALUATION

You are now out of the contractor's plant, working on your recommendations to the contracting officer. As time has allowed, you have examined the available contractor data and the level of efficiency in the plant. Now you have to wade through your findings and come up with direct material costs the Government should pay. To do this, here are some questions you should answer:

- What shrinkage factors are applied? How are they applied? Can data support them? Has the resale of scrap been considered?

- Was a material experience curve used? Is it documented? Is it acceptable?

- Was a make-or-buy program required? Is it complete? Do you agree with all of the contractor's recommendations? Which, if any, do you disagree with? Why?

- Was there adequate competition among outside suppliers to achieve minumum costs?

- Considering storage and handling costs, has the contractor planned to take full advantage of price breaks in his material purchases? Considering storage, handling, and shrinkage, are the contractor's production lot sizes economical?

- For multiyear buys, what protection is offered by cancellation clauses and options? In planning his material purchases, has the contractor shown awareness of multiyear funding and his delivery obligations?

- Do you know the material unit prices recommended by DCAA? Based on your observations of the contractor's make-or-buy, lot-size, and multiyear-buy decisions, do you feel that the recommended unit prices should be adjusted? Have you talked this over with DCAA representatives, and arrived at unit prices the Government should pay?

- Has the contractor or his subcontractors proposed shrinkage allowances for *guaranteed* purchase parts or subcontracted items?

- For standard commercial items--are the costs consistent with market prices? Has ASPR 3-807.1 been adhered to?

- Has the contractor proposed use of interdivisional transfers at other than cost? If so, is the price the established catalog or market price of a standard commercial item, or was it favorable under price competition? Does the price exceed the originating division's price to his most favored customer? For all interdivisional transfers, do the originating and contracting divisions use common overhead and G&A accounts? If so, is the Government being double-charged?

- Has the contractor proposed use of nonstandard parts? Why? Are their costs reasonable?

- Do you feel that repeated design changes may enable the contractor to capture the spare parts business for some items? Have you consulted project office engineers?

- Are any material costs charged to more than one of the following: the plantwide overhead account, a special proratable account, a direct cost account? Are the overhead rates reasonable?

- Have you developed cost recommendations for all direct material elements on the DD Form 633?

- Are you really satisfied?

Subsection III-C. EVALUATING DIRECT ENGINEERING LABOR ESTIMATES

Spotting engineering inefficiencies in the plant is difficult. Engineers deal with concepts. They may appear to be daydreaming when really they are concocting a revolutionary technological breakthrough. Thus your engineering evaluation time may be better spent analyzing contractor data than looking for inefficiencies in the plant.

You can tell more readily which documentation workers are idle. Still, such workers as writers may appear nonproductive when, in fact, they are concentrating on their work. Also the workload the engineers submit determines how busy the documentation workers can be. Worker idleness may be due to a short-term lull in engineering paperwork activity. Because documentation requirements are directly related to engineering requirements, again you may have better results by studying the contractor's data than by looking around his shop.

Management inefficiency is almost impossible to detect in the plant. The level of supervision demanded of each manager depends on such immeasurable factors as attitudes and personalities. You will have to rely on data.

THE PREVISIT PHASE OF YOUR TECHNICAL SUPPORT EVALUATION

EVALUATING ENGINEERING ESTIMATES

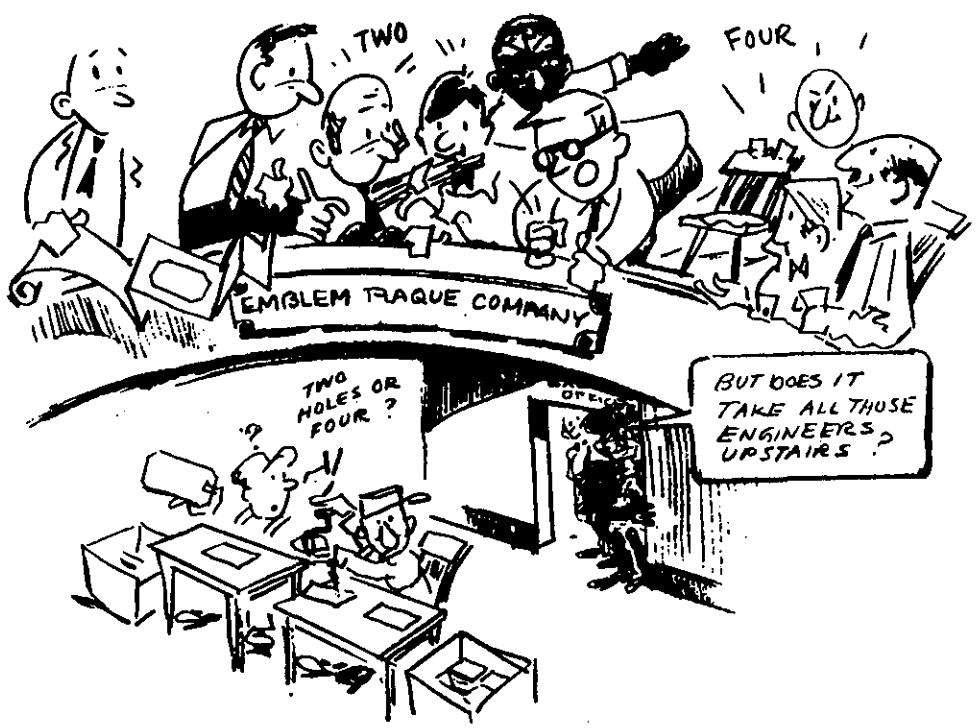
Earlier we told you that when contractors estimate costs it is hard to break the engineering efforts down into specific operations with definite time requirements. In his proposal the contractor probably has not given a detailed breakdown of engineering labor such as he should give for direct manufacturing labor. Instead, his engineering work descriptions will be general, with the number of hours quoted for each effort in much larger time increments than the time proposed for manufacturing operations. For example, he may quote "360 man-hours for design of analog-to-digital conversion circuitry" without giving any further breakdown

Nevertheless, the contractor's engineering estimates should be based on prior work by himself or other manufacturers--work consisting of individual efforts by individual workers. You should try to break down these efforts. The contractor's work descriptions in the basic proposal may be general, but he should be able to supply backup sheets that reveal specific engineering tasks and the grades of the engineers assigned to them. If such sheets do not come with the proposal, you should try to get them once you get to the plant.

Identify the recurring and nonrecurring efforts. If you suspect the contractor has quoted costs for a nonrecurring effort more than once, find out from Government engineers if the effort, indeed, is recurring. If it is not--or should not be--a recurring effort, plan to ask the contractor about it and to tell the contracting officer what you find.

Check the technical support estimate for a complexity factor. If you think engineering change proposals are likely after production begins, you should ensure the complexity factor is not so high as to cover major redesign efforts. ECP's are priced apart from the basic proposal, and the contractor should not be reimbursed for the same design changes in both the basic proposal and the ECP's.

Also check the contractor's estimating techniques. If he has used labor standards to estimate any part of his technical support costs, he should not apply the complexity factor to that part of his overall estimate. Product complexity is considered in the labor standards themselves. Otherwise, a reasonable complexity factor may be applied if a complex end



THE ALERT ANALYST WILL LOOK SHARPLY AT THE COSTS PROPOSED FOR STAFF SUPPORT AND DESIGN TEAMS.

product is to be produced from a Government specification describing only its performance capabilities.

Design Engineering

The solicitation will describe the end product either by specifying its performance or by reference to preexisting hardware designs. If the product has not been produced before, the Government defines it only in terms of what it should be able to do. In such a case, you should expect more design engineering hours than you would if the same or a similar product had been produced previously and was documented.

From the design data package you can identify subassemblies that are common to more than one assembly. A subassembly to be used in more than one assembly should not need complete redesigning for each application. Likewise, you should also watch for material and components that will be used in several subassemblies or assemblies and for which hardware standards have been developed. These standards should be developed only once, not for each item. And they should not be duplicated in the subassembly or assembly estimates.

Manufacturing Engineering

Because the development and implementation of equipment and method improvements should increase the productivity of the contractor's direct manufacturing workers, much of the improvements' costs will be offset by savings in direct manufacturing labor. For example, a contractor may ask for 100 man-hours of manufacturing engineering labor for the development of color-coded assembly instructions that would save him 500 man-hours of direct manufacturing labor.

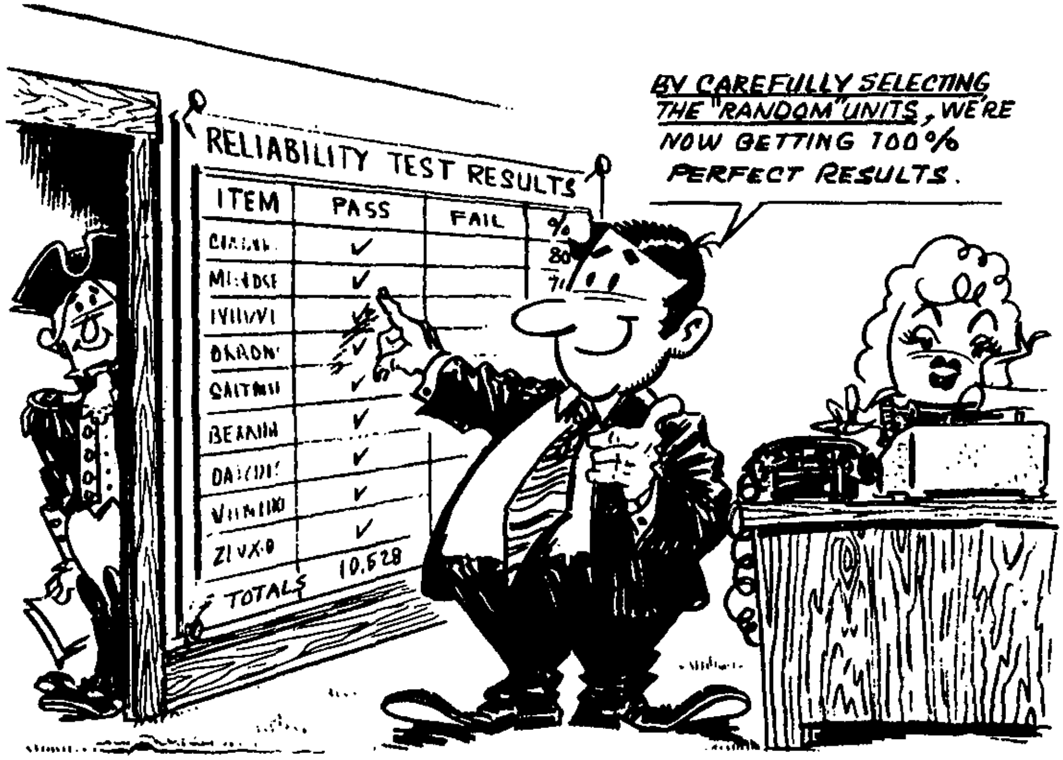
Also look for the contractor's proposing advanced technology when a not-so-advanced technology would be just as efficient and less costly.

Quality Assurance Engineering

Try to break down the total quality assurance effort into specific tasks, such as preparation of a test or inspection standard, design of test equipment, or writing of performance specifications and procedures. Contractor data and the contractor's quality assurance engineers should be able to describe the efforts comprising the total quality assurance estimate. Also, you should try to get records of the contractor's (or other contractors') past quality assurance efforts for similar contracts.

Reliability and Maintainability Engineering

Reliability and maintainability engineering estimates, although in general terms, may be referenced to applicable manufacturing efforts in the proposal. For example, reliability engineering efforts may be refercenced to the manufactured assemblies to which they apply.



COSTS PROPOSED FOR RELIABILITY TESTING SHOULD BE BASED ON CORRECT METHODS OF SAMPLING AND TESTING.

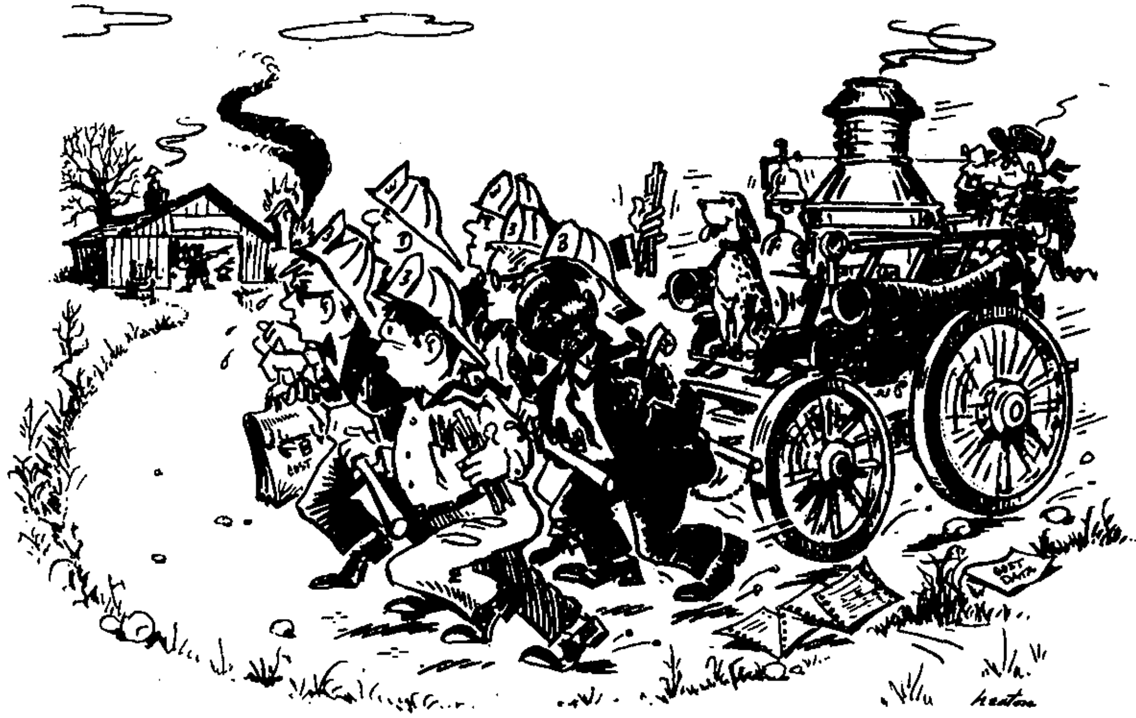
Check for double-charges of reliability and maintainability engineering estimates. You may find, for example, that studies aimed at the manufacture of parts to meet certain reliability requirements have been priced both as a design engineering effort and as a reliability engineering effort. The contractor should be able to show you that these efforts include both design and reliability engineering efforts and are coordinated, not duplicated, efforts by his design and reliability engineers.

Sustaining Engineering

Look for double-charging of single efforts to both "sustaining engineering" and another engineering category.

EVALUATING DOCUMENTATION ESTIMATES

NASA's Data Cost Estimating and Analysis Standard (DM018-012-1), published in 1969, provides excellent guidance on how to estimate costs for documents ranging from electrical schematics to technical manuals. We will not delve into the contents of this publication; we recommend that you read it. We caution you, however, to allow for the cost inflation since 1969 when you look at the cost figures in the book.



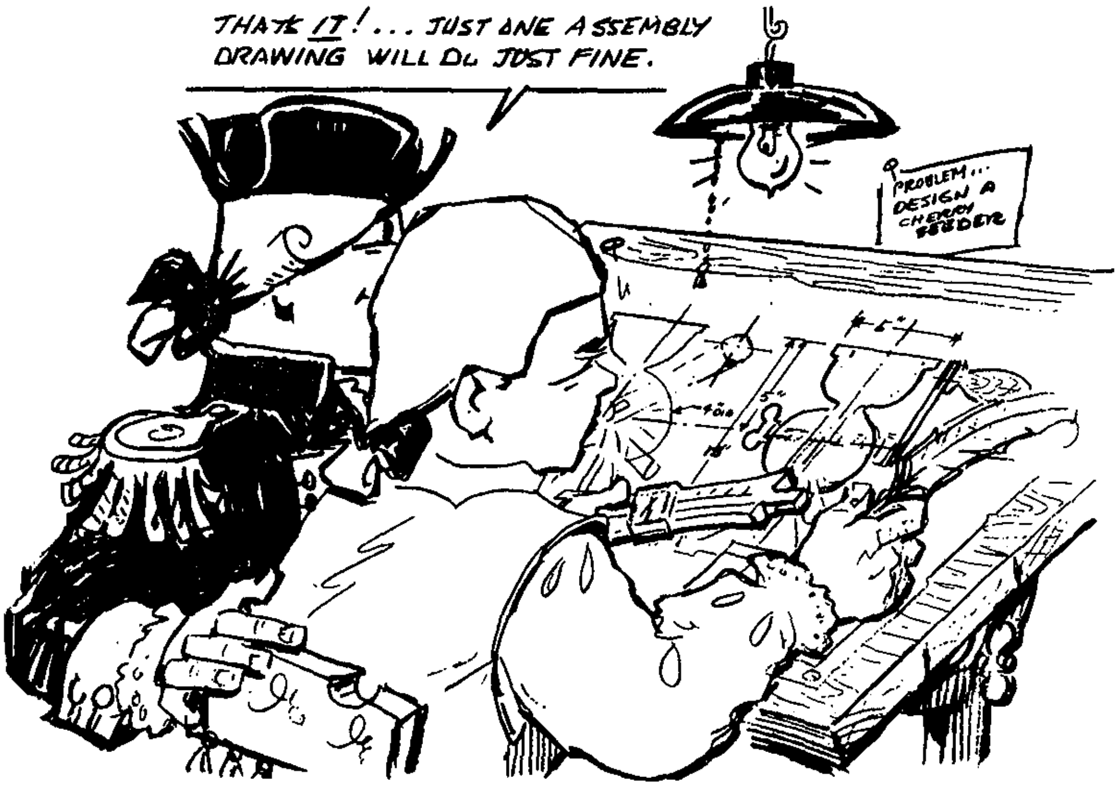
THE PROPOSAL SHOULD NOT INCLUDE MORE SUSTAINING ENGINEERING THAN NEEDED FOR "BRUSH-FIRES".

Finding out what the cost per page represents is your best chance to uncover overcharges. Contractor records and Government experience with similar contracts can tell you about how much and what kind of effort should go into a contract's documentation preparation.

Documentation costs may be included in the design engineering estimate. If they are, you should examine these costs along with the quoted design engineering costs and see if the quoted design engineering efforts correspond with the quoted documentation efforts that supplement them. That is, the design documentation effort should supplement the design engineering efforts specified in the proposal and backup data.

Design documentation efforts should not be duplicated for common components. Whenever a series of near-identical subassemblies is required, each with some small degree of change, look for evidence that standard drawing formats will be used, thus eliminating much copywork.

Suppose a quote for producing a technical document includes the following item:



LOOK FOR STANDARD DOCUMENTATION.

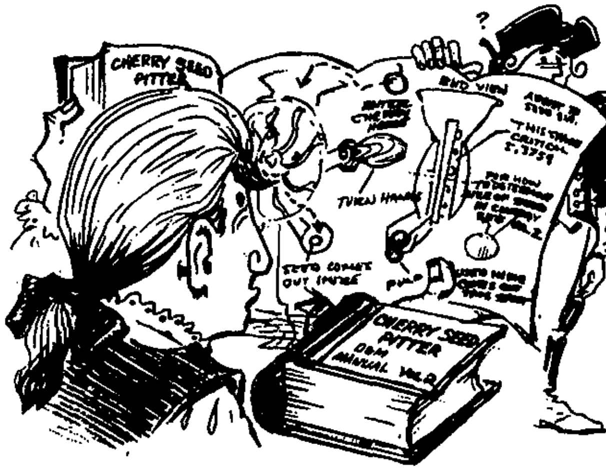
"Reproduction of final draft manuscript: 2500 hours (estimate based on 50 copies of 250 pages at 0.2 hr/page)"

A natural reaction would be that two-tenths of anything could not be much and that the estimate is probably reasonable. Furthermore, you should give priority to potential significant overcharges, and such a fraction as 0.2 certainly does not seem especially foreboding. For that matter, the total document reproduction time, a little more than 1 man-year, probably would not be much compared with the total time required to fulfill the contract.

But look again. The 2500 hours is for but one document, and likely other documents are required on the contract. And 0.2 hour really is not so small; it is 12 minutes, an extravagant amount of time for most methods of reproducing a page. Unless your time is running out and you have more pressing problems, you should take a few minutes' evaluation time to look into this. How many pages will be reproduced for all contract documents? What work effort is the contractor including in his 0.2 hour standard.

A 50 percent decrease in only the reproduction standard should save the Government somewhere between 2500 and 4000 hours, assuming there are two or three more documents similar to the one described. Moreover, because the reproduction effort is overestimated, you may find that other parts of the total documentation effort are overestimated as well.

Separately priced documents and their costs should be listed on a CDRL. For the engineering, drafting, and other costs for producing the documents, you should ensure that these activities would not have been performed anyway during the design and manufacture of the end product.



ANY EXCESSIVE DOCUMENTATION COSTS SHOULD BE QUESTIONED.

The Government could be double-charged if specific tasks quoted in the proposal are for both hardware development and document preparation. For example, a research effort quoted both as a documentation effort and as an engineering effort would be a double-charge. The CDRL should list all costs for producing separately priced documents, and you can use it to check for such double-charges.

EVALUATING MANAGEMENT ESTIMATES

To spot management overestimates, examine the contractor's proposal to see how many managers are proposed and for how long. Then compare these numbers with the numbers you find for the people they manage. Is overmanagement proposed? Government industrial engineers may have to help you.

THE ONSITE PHASE OF YOUR TECHNICAL SUPPORT EVALUATION

During this phase you should try to get data unavailable during the previsit phase. You should try to get as much backup data as you can during the previsit phase, but often you must go to contractor personnel for the information you need. The contractor's historical records, for example, will be hard to get until you get to the plant.

If you have engineering questions for the contractor's personnel, when possible go directly to his engineers rather than his management. Who can better answer engineering questions than the engineers responsible for the work?

Look for obvious technical support inefficiencies. Perhaps certain work areas could be arranged so that workers would not have to walk so far to go about their jobs. Although you may be unable to tell what any one writer or engineer is thinking about at some particular time, you can get a general idea of how busy the workers are by your observations. How much chatting can you hear? Are the restrooms full? Is it break time? Are the pens stroking and the typewriters humming?

Compare the equipment on the floor with the equipment listed in the proposal. See if the new equipment specified in the proposal is already on the floor, and find out how long it has been there. If the equipment has not been installed, much of the labor estimate having to do with the equipment should be for the nonrecurring effort of installation. But if the equipment has been in use for some time, no installation costs should be charged but only the recurring costs for maintaining the equipment.

You can check on documentation by looking at some of the notes the engineers give to the publications people. Writers and editors have to work longer with hastily scribbled, scarcely legible notes than they do with typewritten copy close in format to the finished product. Likewise, draftsmen must work longer and do more layout thinking with a note or comment describing the desired artwork than they do with a rough sketch or a marked-up drawing.

You may also be able to gauge whether or not more effort is being spent per page than is really required. How much work do the changes to existing documents justify? How much can be salvaged? Government workers experienced in publications may be able to help you, if you think you can save the Government a significant amount of money.

THE POSTVISIT PHASE OF YOUR TECHNICAL SUPPORT EVALUATION

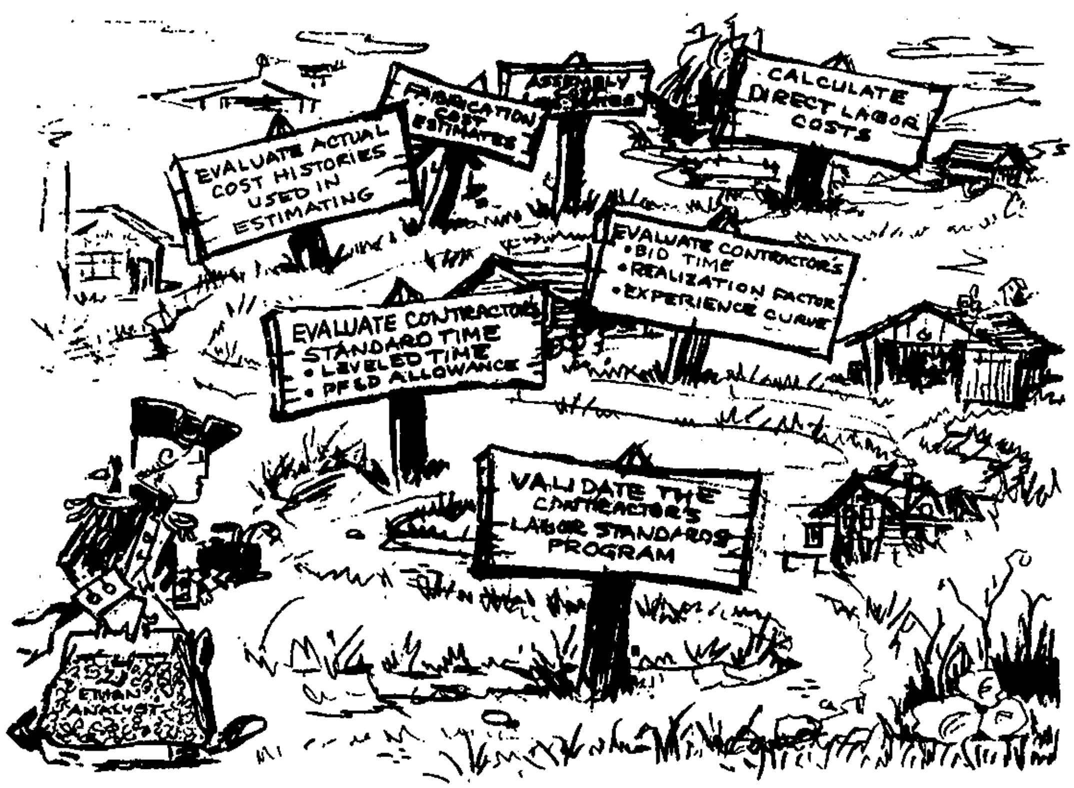
Gather your findings and call contractor or Government experts if you have last-minute questions. Work with DCAA on the hourly labor rates. Then develop your cost recommendations to the contracting officer. Are you satisfied with your recommendation for:

- Design engineering?
- Manufacturing engineering?
- Quality assurance engineering?
- Reliability and maintainability engineering?
- Sustaining engineering?
- Documentation?
- Management?
- The total estimate for DD Form 633 line 4?

Subsection III-D. EVALUATING DIRECT MANUFACTURING LABOR ESTIMATES

THE PREVISIT PHASE OF YOUR DIRECT MANUFACTURING LABOR EVALUATION

Now it is prior to your plant visit. You are examining the proposal and backup data, finding out what you can about the contractor, the proposed contract, and the contractor's cost estimates. When you consider the contractor's direct manufacturing labor estimate, first you should find out whether or not DCAA, DCAS, or other Government or private auditors have analyzed the contractor's estimating data and methods within the past year.



THE ITINERARY FOR YOUR JOURNEY TOWARD A REASONABLE DIRECT MANUFACTURING LABOR COST WILL TOUCH ON ALL ELEMENTS OF BID TIMES.

If the contractor was audited within the past year, get the audit report and determine whether or not the contractor's data and methods were approved. If some data and methods were approved and some "challenged," examine the challenged items. For example, if the contractor uses labor standards, and DCAA judged his PF&D allowance to be overestimated by 15 percent, make sure the contractor either has reduced his allowance by 15 percent or adequately explained why not.

Also give some attention to approved items. Estimating data can become invalid if the contractor's manufacturing methods or plant conditions change. In the contractor's proposal and backup data, you should look for evidence of such changes occurring since the last audit or planned for the near future, while the proposed contract is in progress.

If no audit was performed within the past year, if auditors challenged the contractor's entire estimating system, or if you find evidence of major changes in manufacturing methods or plant conditions, you should take a closer look at the direct manufacturing labor estimates.

EVALUATING ESTIMATES BASED PRIMARILY ON HISTORICAL DATA--PREVISIT PHASE

Some contracts call for a partially new product, which the contractor has not made before but which contains items he has made. For the items he has made or is making, reasonable actual times or costs are acceptable as bid times or costs, provided that no procedure changes have occurred or are anticipated. For the items he has not made, his bid times should be based on his history in producing similar items, plus any reasonable factor necessary to account for differences in product requirements. He should be able to substantiate any such factor.

Remember that personal needs, fatigue, unavoidable delays, and rework are already accounted for in "actuals." Unless the contractor submits convincing data, verified by DCAA, that such time requirements are accounted for separately, do not accept addition of such allowances or factors to actuals used as bid times.

Experience curves can be used in this estimating system. If so, they should be based on approved actuals. (We discuss experience curves again in this subsection.)

EVALUATING ESTIMATES BASED PRIMARILY ON LABOR STANDARDS--PREVISIT PHASE

Leveled Time

In the proposal data, look at how the contractor determined leveled times. Examine the number of time studies or work samples to establish whether or not the contractor made enough studies or samples to develop accurate leveled times. You may need help from Government industrial engineers to do this.

To evaluate leveled times based on predetermined standards, compare the predetermined standards the contractor used with those in industry publications (see the bibliography). Also, find out if the contractor has attempted to level any operation times based on predetermined standards. Predetermined standards themselves are leveled, so no leveling factor should be applied to operation performance times determined by combining predetermined standards.

Allowances

A contractor may allow for such work as work-station cleanup and minor minor machine maintenance in either a PF&D allowance, a special allowance, or a realization factor. Make sure, however, that he does not duplicate the time allowed for any such effort. Unpredictable or avoidable delays should not be covered in the allowances or the realization factor.

If you find a contractor using a special allowance to compensate for unusual working conditions, examine his backup data. Ensure that no extra time is included in the leveled time or another allowance to account for the special working conditions.

Claiming that they do not operate under conditions identical to those

UNPREDICTABLE DELAYS FROM FLOOD . . . FIRE . . . ETC . . . MAY NOT BE COVERED IN THE ALLOWANCES OR THE REALIZATION FACTOR.

under which predetermined standards were developed, some contractors use special allowances to adjust leveled times developed by such organization as the MTM Association for Standards and Research. The conditions indeed may differ, but you should ask what the differences are and why they exist. Because predetermined standards are developed under typical shop conditions, you should not allow adjustments unless the contractor can explain why he operates under less-favorable conditions. If the contractor really cannot operate under better conditions, and his explanations are good, you may accept a small allowance.

A contractor who presents no data to back up a special allowance may have relied on an engineering estimate rather than time studies to determine the allowance. If such is the case, plan to ask the contractor to explain his estimating procedure. Should he be unable to convince you that his method has produced an acceptable allowance, develop your own estimate of the allowances, if you think an allowance is justified.

Realization Factors

Ordinarily, the experience curve represents actual performance. When the experience curve is used, no realization factor should be applied to the curve because "realization" is considered in the curve itself (see figure III-D-1). (There is an exception, which we discuss later in this subsection.)

A realization factor of greater than 1.00 means that work is below standard. If the contractor is proposing bid times that are greater than standard, try to find out why from the contractor's backup data.

A contractor may apply a realization factor to account for below-standard work owing to the inexperience of newly hired employees is acceptable, but you should check his labor rates. Remember, his proposed pay rates should be the average of the rates paid during the lifetime of the contract. Lower wages should be paid to inexperienced workers, thus reducing the average.

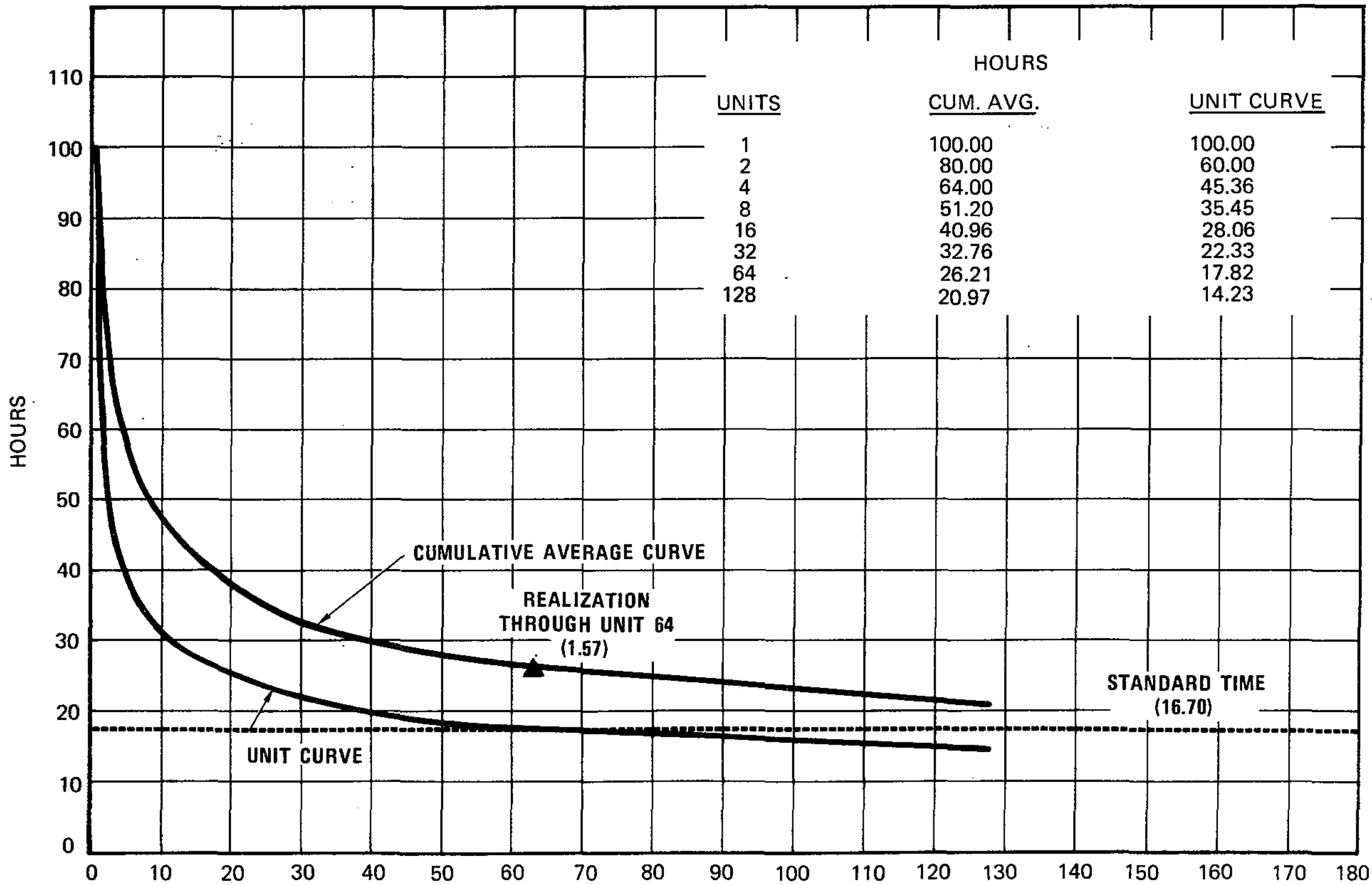
Efficiency Factors

Efficiency factors and realization factors are twins in purpose, but they are mathematical reciprocals. A realization factor is actual time divided by standard time. An efficiency factor (actually, an allowance) is standard time divided by actual time. Confusion could be costly.

Experience Curves

Check the contractor's mathematics. (See appendix A for how.) If his math is all right, go on to his data.

The contractor's unit one and curve slope should be based, if possible, on his organization's past production of identical or highly



UNITS	HOURS CUM. AVG.	HOURS UNIT CURVE
1	100.00	100.00
2	80.00	60.00
4	64.00	45.36
8	51.20	35.45
16	40.96	28.06
32	32.76	22.33
64	26.21	17.82
128	20.97	14.23

similar end products--in other words, on his own history. If he lacks such data, he can develop his own unit one from reasonable standard times and slopes based on published industrial data.

In his proposal data, the contractor should identify the sources for his curves. If his sources are not identified, be sure to ask for them when you arrive at the plant. You can choose your own sources for cross-checking the contractor's sources. As you gain experience in evaluating experience curves, you will develop a "nose" for what a reasonable experience curve would be for particular types of work.

The Slope of the Curve. The contractor *must* substantiate the proposed curve slope with historical data, either his own or someone else's. He should not select one slope from one contract (unless his history is that limited) and propose that slope for the contract you are evaluating. The proposed slope should be an average slope for similar or identical production.

When substantiating data are unavailable, the validity of the curve slope becomes the cost analysis team's opinion versus the contractor's. An area for negotiation has been found.

Unit One. If a contractor quotes a steep slope, he is saying he will gain experience more rapidly than he would had he used a shallow experience curve slope, but look at his unit one if he does. An 80 percent experience curve is more impressive than a 90 percent experience curve, but a steep experience curve can be offset by a high unit one. For example, if an 80 percent curve is applied to a unit one time of 100 hours, when the 50th unit is produced the time required for each unit will be 28.38 hours. If a 90 percent curve is applied to a unit one of 52 hours, when the 50th unit is produced the time required for each unit will be, again, 28.38 hours.

Unit one is determined either by actual production of one unit or by projecting a theoretical unit one back from standard time by means of the curve. The contractor should show either that his *actual* unit one is reasonable, based on his historical data, or that his labor standards and

A SLOPE SHOULD NOT BE CHOSEN BLINDFOLDED!

THE CONTRACTOR SHOULD NOT RESTART AT UNIT ONE WITHOUT THOROUGH JUSTIFICATION.

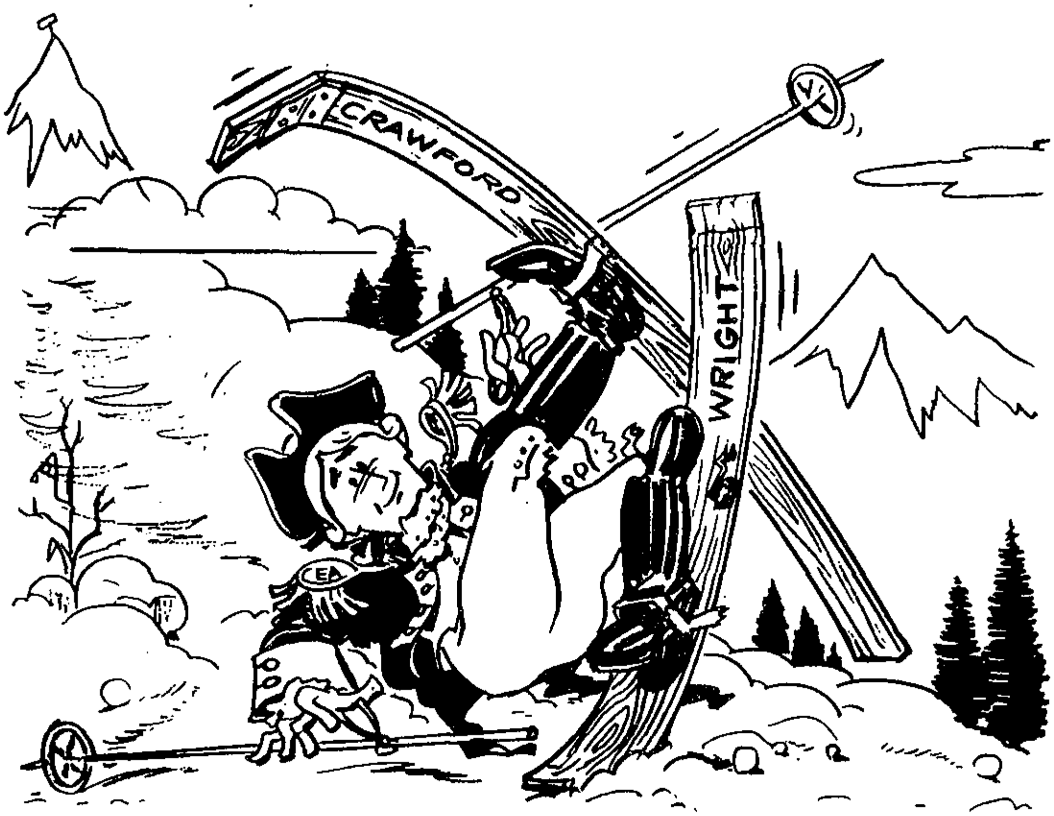
IN GOING TO A THEORETICAL UNIT ONE, THE CRAWFORD ROUTE WILL TAKE YOU TO THE LOWER VALUE.

curve slope are valid and are used correctly to project a theoretical unit one.

Unless a contractor can prove that his plant is totally inexperienced at making a particular product, do not accept estimates starting from unit one. Production breaks may cause some loss of experience, but once a contractor has significant experience at producing a particular product he is not likely to lose all of that experience.

The Wright Method versus the Crawford Method. When actual unit one data are known, the Wright Method usually benefits the Government more than the Crawford Method does. Conversely, when developing a theoretical unit one from a given labor standard, use of the Crawford Method usually is more beneficial to the Government. Nevertheless, in the absence of conclusive data, apply both methods and advocate the method that is fair to both parties. If you suspect the contractor's unit one is incorrect, you can check it by plotting a Crawford curve.

Examine how the contractor collects data for his curves. If he accumulates data by the Wright cumulative average method and proposes costs by the Crawford unit method, his cost estimates may be inflated by as much as 30 percent. (See appendix A.)



CONTRACTORS SHOULD USE ONE METHOD TO ACCUMULATE DATA AND ESTIMATE COST.

The Experience Curve and Standard Time. In theory, a shop's or a worker's "learning" never ends. Eventually, however, the mere gaining of knowledge and experience becomes a negligible factor on productivity. The curve "flattens out."

But before a curve slope levels off, shop performance should equal or surpass standard. Such things as worker turnovers and the addition of new, inexperienced workers should be offset by procedural innovations and the continuous improvement of workers who have been around long enough to exceed standard performance.

The point at which the experience curve is projected to cross standard time is of utmost importance. The Government pays the labor cost per unit of product at the end of the contract. Until the curve crosses standard, work is substandard. If the contractor produces 999 units of a product, and standard performance is projected for the 1000th unit, the Government pays for less than standard performance.

The Experience Curve and Realization. When we discussed realization factors, we said that usually the curve represents "realized" performance, requiring no factoring to determine the actual performance time at any point on the curve. On a few occasions, however, you may find a contractor using a curve representing productive performance only, not including time for taking care of personal needs, resting, or unavoidable delays.

In such a case, the contractor can plot productive performance time to any point on the curve, from unit one to "standard" (should-take) performance time to contract's end. Then, to propose a bid time, he can apply an allowance or factor to the point on the curve for which he needs to determine "realized" performance time, including acceptable nonproductive time. He can call this allowance or factor a PF&D allowance, a realization factor, or anything else he wants to call it, as long as his estimates are fair.

It would help if the allowance factor were analyzed and approved by prior audit. Then you could focus on making sure the curve, in fact, represents productive time and does not already include nonproductive time. If the allowance or factor has not been verified, you will have to check it out. You do this in the same manner we describe for evaluating allowance and factors applied to leveled time and standard time, making sure allowed times are not duplicated. You evaluate the productive time in the curve by reviewing cost data on similar items and later, by onsite observations of similar efforts.

Rework Factors

Rework factors should be supportable by abundant historical data. The contractor should not select a rework percentage from a few contracts or short time periods. One year's accumulated data should provide a reliable index of a contractor's plantwide historical percentage of rework.

Also, if the Government is paying for high-cost/high-reliability material in direct material costs, the contractor should return any defective material to the supplier who sold it to him, and get reimbursement. The Government should not pay for rework of such material.

Selecting Samples in the Previsit Phase

During the onsite phase, you will verify bid times for certain operations by measuring the performance times you observe for identical or highly similar operations. You will not have time to measure the time for every operation in the proposal. Instead, you will have to pick out a few operations, check out the bid times for those operations, then generalize your findings. If you find mistakes repeating themselves in the few bid times you analyze, you should ask the contractor to show that the mistakes do not prevail in all his estimates. If he cannot do so, he should adjust all of his bid times.

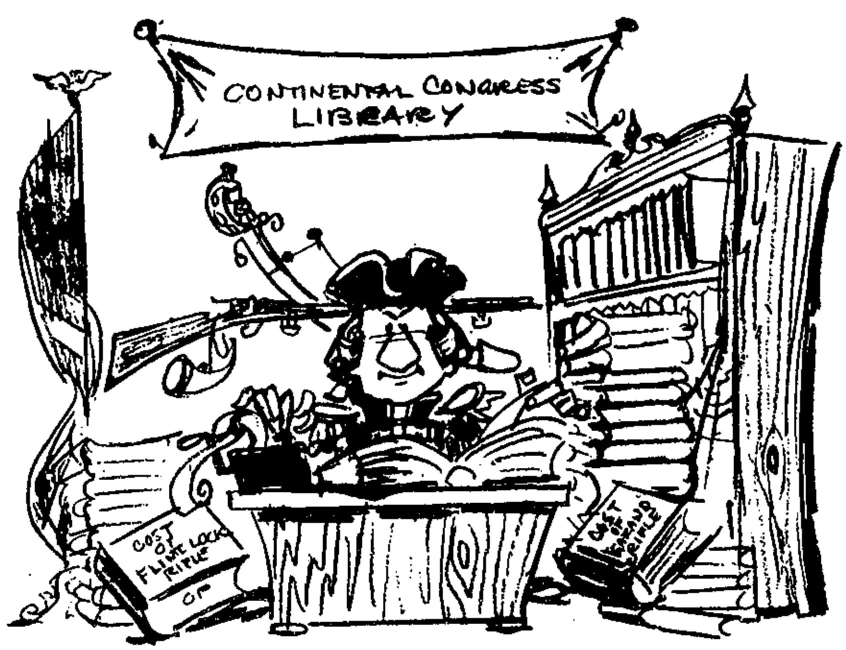
Remember, it is wise to document findings on items offering the greatest potential for savings. You should take your samplings from operations that are costly to perform or that will be performed many times, resulting in a high total cost. The previsit phase of your direct manufacturing labor evaluation is your chance to select costly operations for your onsite analysis.

THE ONSITE PHASE OF YOUR DIRECT MANUFACTURING LABOR EVALUATION

EVALUATING ESTIMATES BASED PRIMARILY ON HISTORICAL DATA--ONSITE PHASE

Actual times are records of the time it took to perform certain operations by specific methods under certain conditions. If a contractor changes his manufacturing methods or conditions within his plant, likely his actual times will changes. The actual times he has on record cannot be used for estimating bid times, unless the changes are so small that the actual time can be factored to account for the difference in performance time. If the changes are major, actual times become as outdated as last year's calendar.

In the previsit phase, you should have accumulated the available historical data and examined it to determine the contractor's past production methods and working conditions. Early in the onsite phase, gather and examine the historical data you could not get earlier. Document your findings. Beginning with the initial plant tour, compare the production methods and plant conditions cited in the contractor's history with the methods and conditions you observe firsthand.



THE CONTRACTOR'S HISTORICAL DATA ARE ESSENTIAL TO YOUR ANALYSIS.

What if the contractor says his PF&D allowance was underestimated? The 10-minute rest period was the only interruption you observed, so you should ask the contractor why he needs a greater PF&D allowance. Even if he can support some increase in his allowance, his proposed leveled time is 194 percent of the average time you observed. To claim an additional 94 percent of the leveled time as a PF&D allowance would mean that nearly half of the proposed leveled time would have been nonproductive. Such a leveled time would be too loose for acceptance.

You did not spend a whole workday observing worker performance. You should expect some PF&D allowance besides the 10-minute rest period you observed. But even if 25 percent of the observed performance time (0.17 hour) is added as PF&D allowance, your standard *time* would be only 0.21 hour--still significantly less than the proposed *leveled* time of 0.33 hour.

Suppose the contractor made a mistake. The 0.33 hour, he says, is his standard time for the operation, not his leveled time. He says that his leveled time, indeed, is 0.17 hour and his PF&D allowance is 25 percent of his leveled time, giving a total of 0.21 hour. Then, he says, he must apply a special allowance of 57 percent of the 0.21 hour, which gives him his 0.33-hour standard time.

In other words, out of an 0.33 hour standard, the contractor would be allowing 0.12 hour for "special" production delays. In addition to his PF&D allowance, he would be allowing 36 percent of his standard performance time for nonproductive time. Combining his PF&D and special allowances, 94 percent of the proposed standard time would be allowed for nonproductive time. You should not accept this unless the contractor can thoroughly justify it.

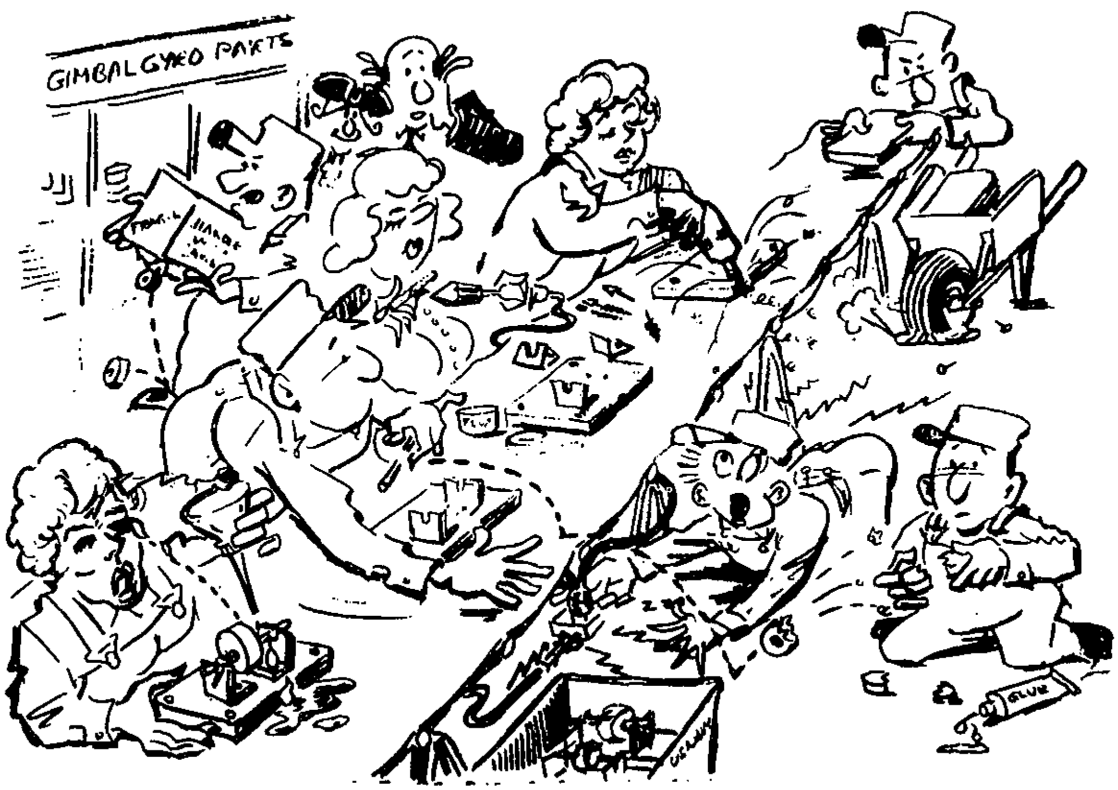
Another way to evaluate leveled time is to compare the machine feed rates specified on the contractor's process sheets with the actual feed rates you see in his machine shop. Remember that fabrication cost estimates of machining operations are based on the feed rates specified in industrial engineering standards. If workers discover they can increase the feeds and speeds on their machines beyond the values listed on the contractor's process sheets, "inflated," or "loose," labor standards will result.

You must become familiar with the process sheet for a given part before you begin the floor evaluation. When you know where on each machine the feed control setting is located, begin observing feed setting on as many machines as you feel represent the shop conditions.

Suppose a process sheet operation description calls for a metal-cutting machine operator to maintain a feed rate of 9 inches a minute. You observe that the cycle time is 2 minutes--1 minute for loading and unloading the machine and 1 minute for metal removal--and that the feed rate actually is 12 inches a minute. Because the cutting of the metal represents one-half the total cycle time, the operator's increasing his feed rates by 50 percent should result in a 25 percent increase in actual output. In checking the operator's output reports, however, you probably will find that his production is closer to 100 percent of that expected than to the 125 percent of which he is capable. Workers probably would rather have free time than have the recognition of increased productivity, because with that recognition would come revised feed rate recommendations and increased management expectations.

Your On-the-Floor Evaluation of the Allowances

Check one or two of the contractor's allowances when you are on the shop floor. If you check a personal allowance, note the distances from drinking fountains and toilets to the work areas. If you check a fatigue allowance, note the lighting, heating, air-conditioning, and cleanliness of the work area; the danger involved in the job; and what position the operator must work in. If you check a delay allowance, do not permit a startup or a cleanup time in a PF&D allowance (or special allowance) to be duplicated in a realization factor. If you check a special allowance, make sure the time compensated for in it is not compensated for in some other allowance.



SLOPPY WORKMANSHIP RESULTING IN DELAYS SHOULD NOT BE ALLOWED.

If a contractor tells you that part of his delays are because he does not have enough lift trucks available to bring work to a given area, that should be his problem and not the Government's. The cost of buying or leasing additional lift trucks may be offset by the money the contractor saves by reducing lost labor time.

If a contractor allows his employees to take unlimited breaks, again that is his business and he should bear the burden of the cost. Two 10-minute breaks a day are reasonable for most kinds of work. Sometimes heavy work necessitates longer than 10-minute breaks. But even so, you should ensure that his personal allowance does not duplicate elements in the fatigue allowance. And if employees wander about the shop, if the restrooms remain densely populated throughout the day--especially by nonusers--or if you think too much time is wasted in chatter, you should question the contractor's allowances.

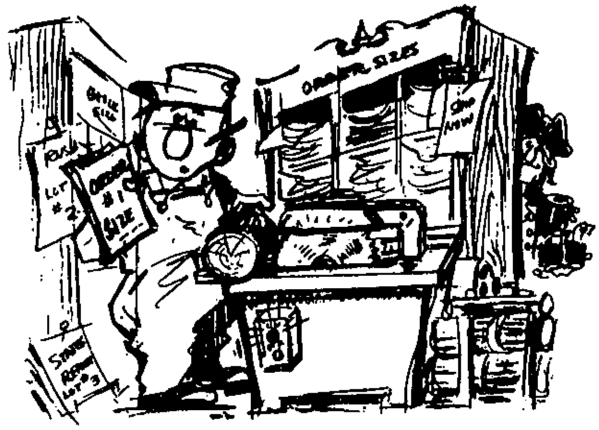
Your On-the-Floor Evaluation of Realization Factors

Review the historical data the contractor used to get his realization factors. Did he accumulate actual times from a department performing a process that consisted of several operations? Did he accumulate actual times of each of several workers performing a single process, then determine an average "actual" time for their performance? Did he accumulate actual times on several performances of one worker doing a specific operation? Or did he determine the actual time one worker spent performing the operation?

A one-worker sample may be adequate if only a few workers must perform an operation or process a few times during the contract. Still, you should sample other workers' performance times for the same process to make sure the realization factor is based on a representative actual time. If the contractor determined how long each of several workers took to perform a process, or if he measured several performances of one worker performing one process, see if unusual variations exist between individual measurements. If so, ask why.

For contracts that require many complex processes, departmentwide realization factors may be acceptable time-savers. Such a realization factor would be based on the actual time of a whole department performing an entire process, which may include several operations. If so, the realization factor will be the average realization of all the operations in the process. If the contractor lists some of the operations in his proposal, but not all, he should account for any significant differences in realization for the individual operations and realization for the total process.

Inefficiency. A high realization factor indicates a wide gap between standard and actual performance, which suggests shop inefficiency. Some reasons for inefficiency are:



TOO MUCH PAPERWORK EQUALS TOO MUCH TIME.

- Employee abuse of mail-delivery and phone privileges during production time

- Excessive service times and requests for service at tool cribs

- Use of inexact jigs and fixtures from a prior similar job

- Inadequate support personnel, which causes operators to perform indirect jobs such as material handling and restocking

- Ratio of indirect to direct workers out of proportion

- Excessive housekeeping before and after shifts, breaks, and lunch periods while working on continuous operations

- Poor housekeeping methods and excessive scrap

- Excessive paperwork by labor rather than management, which results in a general operator inefficiency

- Expected output not communicated to employees

- Lack of low-cost power tools, such as suspended pneumatic screwdrivers

- Tool storage and line stock storage areas located remotely from production area

CRAMPED ASSEMBLY STATIONS CAUSE INEFFICIENCY FROM EXCESSIVE PERSONAL CONTACT AND LACK OF STORAGE SPACE.

- Improper arrangement of fabrication work stations, which impedes work flow (see Figure III-D-2)

- Improper arrangement of tools and material at work stations (they should be arranged in the order in which they are used)

- Hand motions not replaced by foot pedals when possible

- Drop delivery of finished item or scrap not used where possible

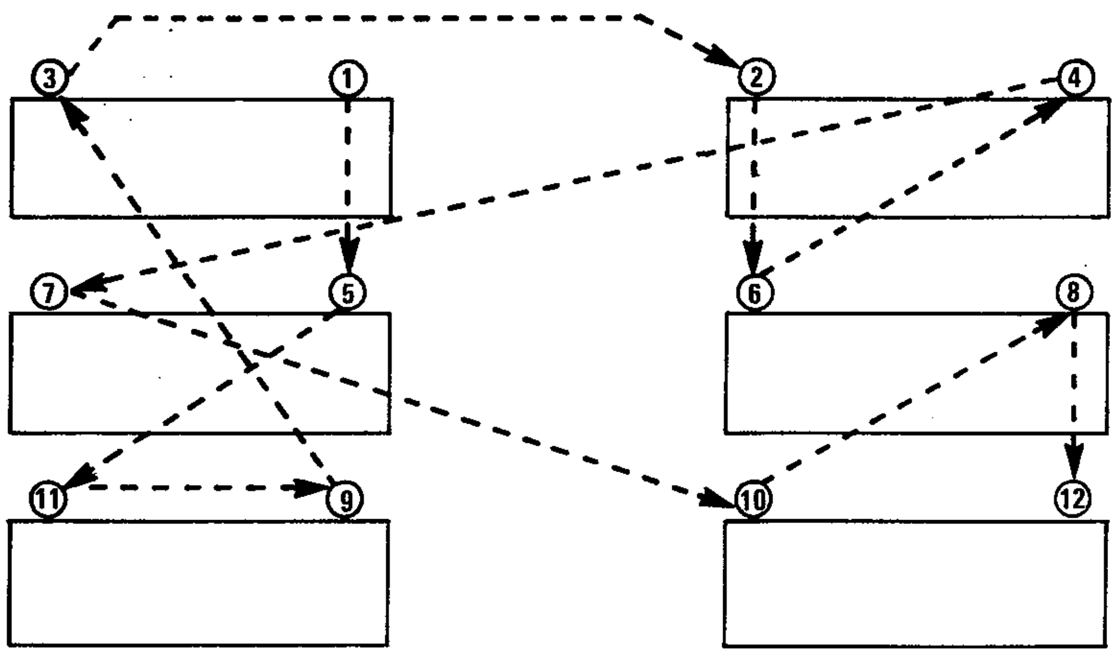


Figure III-D-2. Inefficient Work Flow
(Circled Numbers are Work Stations)

- Gravity feed of materials and components not used where possible

- Raw-material storage areas not fully stocked at beginning of shifts

- Too many elements per operation, which prohibits memorization of required element sequences and the development of an efficient assembly rhythm, or cycle

- Not enough elements per operation, which causes excessive handling time

- Components and raw material not mass-preconditioned prior to subsequent operation, which causes delays in individual elements of the operation

- Assembly stations located too close to each other, which creates excessive personal contact, lack of storage space, and cramped conditions

- Assembly stations located too far apart, which causes excessive handling of material and isolating workers

- More or less production in an adjacent assembly-line operation, which causes an unbalanced assembly line and idle operator time

- Lack of standards or output goals in the production shop

- Lack of methods analysis function, which creates:

  (a) Temporary operator-fashioned tools and accessories

  (b) Inconsistent work methods from day to day, operator to operator, and operation to operation

  (c) Slow learning or learning by trial and error

  (d) Undue operator fatigue and complaints

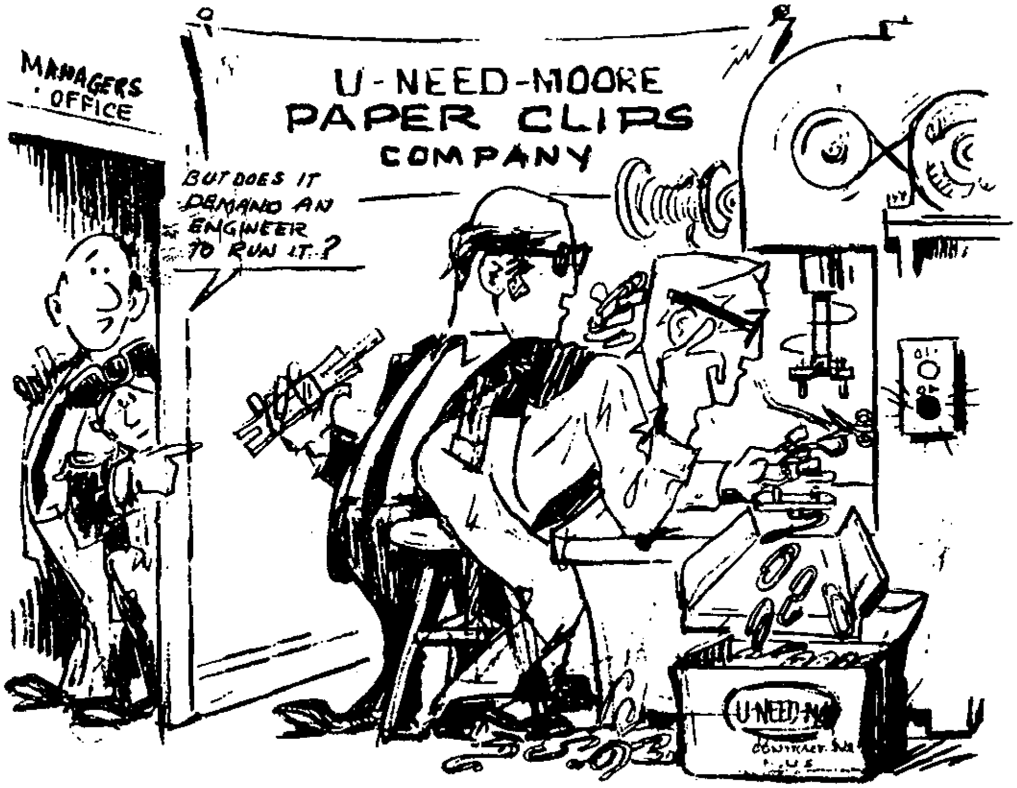
  (e) Poor design of workplace, parts bins out of reach, and clumsy or inapplicable tools and fixtures

- Low-wage employees when operation requires highly skilled workers

- Highly skilled, highly paid workers when less-skilled workers can do the job

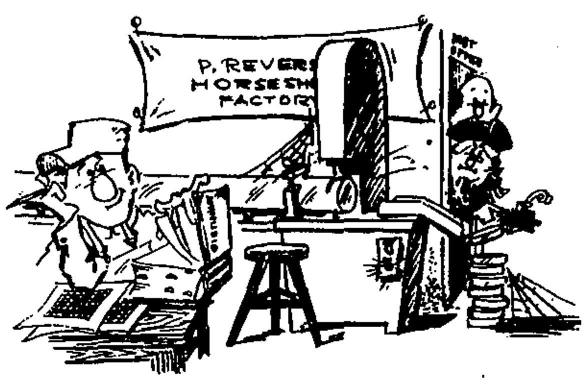
- Incomplete contractor process sheets

- Generally poor work pace because of poor worker attitudes, worker failure to follow prescribed methods, and so on



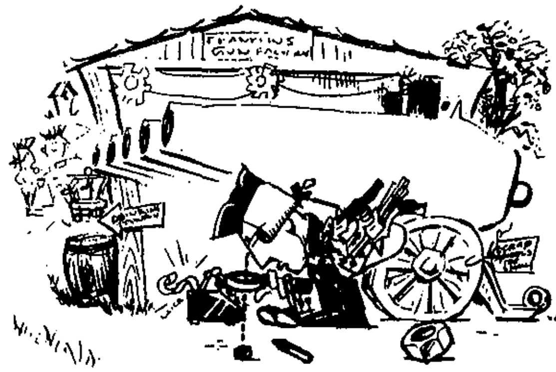
COMPARE JOB TITLES AND PAY GRADES FOR RANDOMLY SELECTED WORKERS WITH WHAT YOU BELIEVE THE WORK JUSTIFIES.

Onsite observations are necessary for identifying these sources of inefficiency because they are not always obvious from the contractor's data. Later, you may want to quantify your observations. For example, if you feel a shop's production is reasonable or average, you could rate it at 100 percent. But if you observed conditions that you felt were unreasonable, you could rate the production at, say, 80 percent. What you are doing is constructing a rationale with which to refute realization factors that compensate for inefficiency.



INEFFICIENCY CAN BE SEEN IN A GENERALLY SLOW WORK PACE.

Suppose the contractor has a realization factor of 1.20 and you rate his production level at 80 percent. You have nullified his realization factor. If his realization factor had been more than 1.20 and you rated this production level at 80 percent, you would not completely nullify realization factor but you would have determined that at least part of it results from inefficiency.



LOOK FOR THE SMALL AS WELL AS THE LARGE CONTRIBUTORS TO OVERALL SHOP INEFFICIENCY

Prepare for your observations by selecting a typical work station. Do not permit the contractor to select his most efficient work station, but neither should you observe an inexperienced operator who is using antiquated equipment.

Now gather data that describe the the operation performed at the work station, historical data on both machine and operator, the projected work schedule of the work station, and such other data as drawings of parts currently being fabricated and related process sheets. Then, observe the work station operator.

If you spot any inefficiencies, document them on a "data sheet for sources of inefficiency" (see figure III-D-3). Try to rate the level of efficiency for each operation you observe, as we described above. If the machining of low-quality castings at a given work station causes high rework and scrap rates, document these inefficiencies on your data sheet and use your notes as the basis for rating the efficiency at the work station.

When you are satisfied that you have seen enough to determine the average level of efficiency at a work station, observe other stations. Document their inefficiencies until you are satisfied that you are familiar with the shopwide efficiency level. If particular inefficiencies are observed in several work stations, you must assume that they affect production of the whole shop.

Now let us talk about the data you should put on your data sheet for sources of inefficiency.

General Data. General data are equipment, worker, or procedure descriptions that cannot be categorized within your specific data list but that should be filed by you for future reference. During your evaluation of a contractor's shop or while you perform several evaluations, you may find one or more general data items becoming constant. If you are assigned to a few contractors who produce similar products, you may wish to organize your general data file according to type of component or specific shop area.

Specific Data. These are:

- Part/assembly number and name, which can be obtained from the paperwork associated with the parts and the work station

GENERAL DATA

- Contractor
- Contract description
- Shop area
- Type of production
- Name of product/part

SPECIFIC DATA

- Part/assembly number
- Part/assembly name
- Work station/machine type
- Equipment model/make
- Operation description
- Quantity per lot
- Quantity per contract
- Rework history
- Direct labor per part
    - Quoted
    - Actual
    - Recommended
- Operation variables
    - Feed per inch
        - Quoted
        - Actual
        - Recommended
    - Number of parts at one time
        - Quoted
        - Actual
        - Recommended

COMMENTS

- Reasons for inefficiency
- Projected machine/work station load (hours)
- Estimated percent difference in direct cost
- Prior contract quotes/actuals

Cost factors	Excessive	Percentage	Satisfactory
Leveled time	---	---	X
PF&D Allowance	X	2	
Realization factor	X	2	
Rework history	X	2	
Material attrition	---	---	X
Direct tooling	---	---	X
Learning (remaining)	---	20	

Note: Date entries are hypothetical.

Figure III-D-3. Data Sheet for Sources of Inefficiency

• Work station/machine type, including such descriptions as automated, manual, tape-controlled, drill press, and turret lathe, which can be derived by observation or from an engineering list of equipments

• Equipment model/make, a record of equipment age and manufacturer, which you should be able to find from direct observation, process sheets, and other contractor data

• Operation description as quoted by the contractor, which should be in the process sheets that follow parts through the shop

• Quantity per lot. A quick test of the contractor's economic awareness can be made by calculating the economical lot quantity, as described in appendix B, and comparing this calculation with the quantity being run on the floor. The quantity per lot can be obtained from a master schedule or from on-the-floor observation.

• The quantity per contract, a parameter in the economic lot quantity calculation, which can be obtained from either the master schedule or the master bill of materials

• The contractor's rework history, which he should make available upon your request. Examine the operation to determine how a high or moderate rework factor can be reduced. Rework can be the fault of a labor, an engineering, a quality control, or a management group, and the fault should be determined to eliminate rework as much as possible.

• Direct labor per part by the following categories: (1) quoted, (2) actual, and (3) recommended. You can obtain the quoted labor from the contractor's backup sheets or from his process sheets. The actual labor per part can be determined either from the operator's output records or from an on-the-floor stopwatch check. Based on your observation, such parameters as feed rate, work methods, and lot size can be revised and your reasons for revision noted under "comments" at the end of your data sheet. Then, based on your revisions, you can derive a recommended labor rate for this operation.

• Operation variables, which are documented in the same way as is direct labor. The variables will be important in later discussion with the contractor about discrepancies between his and your estimates of reasonable labor content. You should determine whether such operation variables as feed rate and number of parts per cycle are left to the operator or are specified in the process sheets. If they are specified, the variables directly affect the quoted leveled time. If they are not specified, any inefficiency could be attributed to less than optimum work methods and may show up in a realization factor or false experience curve.

Comments. The items listed under "comments" on your data sheet, except for "prior contract quotes/actuals," have been mentioned. If estimated or actual data exist from the product or operation in question, such as from prior contracts, these data should be compared with the data on your data sheet. If an operator could stack and drill four printed circuit boards in one stroke last year, he can surely do the same this year.

Opportunities for Increased Efficiency. Opportunities for increased efficiency are chances to improve utilization of a direct laborer's time when, because of production conditions, he is placed in a nonproductive position, such as during:

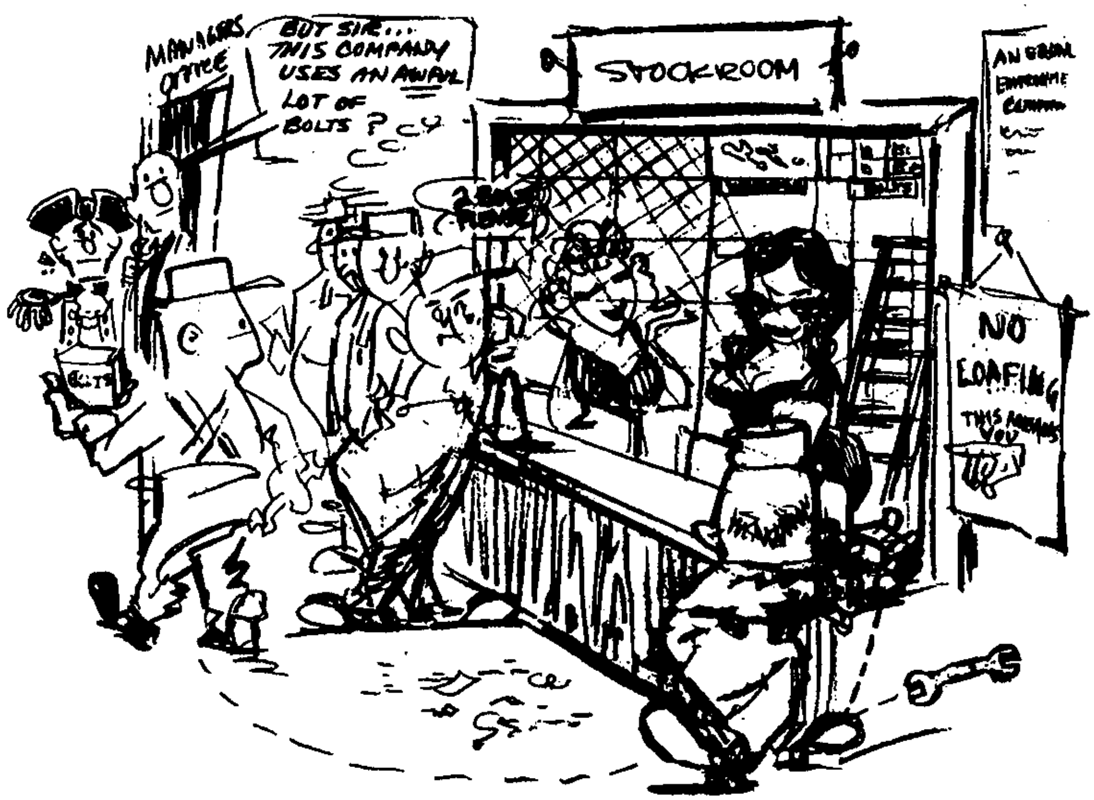
- Machine downtime (machine is inoperable)
- Machine-controlled time (machine is operating automatically)
- Time waiting for tools, work, or assistance

Imagine a bandsaw operator cutting a 3-inch-diameter steel bar into 1/2-inch-deep discs. Each cut takes from 5 to 7 minutes. During this time, the operator is idle, except that when the machine cycle ends he makes sure the material automatically advances. For an order of 20 parts, production would require about 2 hours of machine time. During this time, the operator is standing idle about 1-3/4 hours. This time is an opportunity for increased productivity. The operator could use this time to complete paperwork, to arrange material, or to set up for the next job.

Somewhere about any machine shop should be a tool crib where you can perform an informal time study. Answer the following:

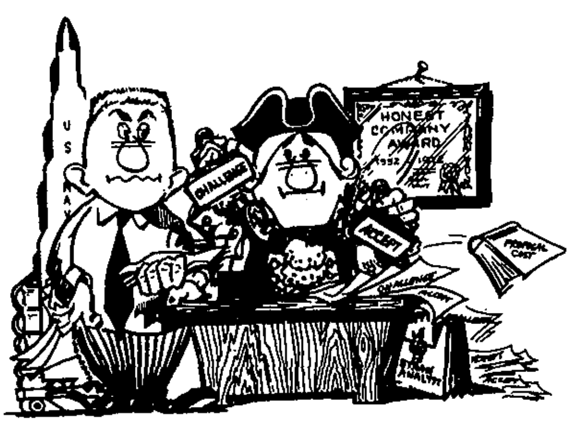
- How often do operators come to the crib?
- How much time do operators spend getting the attendants' attention and receiving service?
- How often do operators leave the crib dissatisfied because a tool was not in stock, they had the wrong tool identification number, or similar causes?
- How many attendants are at the crib?

Numerically controlled machines are a major source of operator idle time. These machines operate automatically once supplied with a programmed tape. During an operation cycle, which can last up to an hour, the operator needs only to load and unload the machine and start the cycle. One operator should be able to run several machines, but the contractor may not allow this because close observation is required to prevent unexpected damage to expensive parts and tools: operators, however, should be productive in some supporting way while the machine fabricates the part.



ONE SOURCE OF SHOP INEFFICIENCY MAY BE EXCESSIVE SERVICE TIMES AND REQUESTS FOR SERVICE AT TOOL CRIBS AND STOCKROOMS.

THE POSTVISIT PHASE OF YOUR DIRECT MANUFACTURING LABOR EVALUATION



YOUR JOB IS NOT MERELY TO FIND FAULT, BUT ALSO TO VERIFY THE CONTRACTOR'S ESTIMATES.

Review your findings on the contractor's:

- Actuals
- Leveled times
- PF&D allowances
- Special allowances
- Realization factors
- Efficiency factors
- Experience curves
- Rework factors

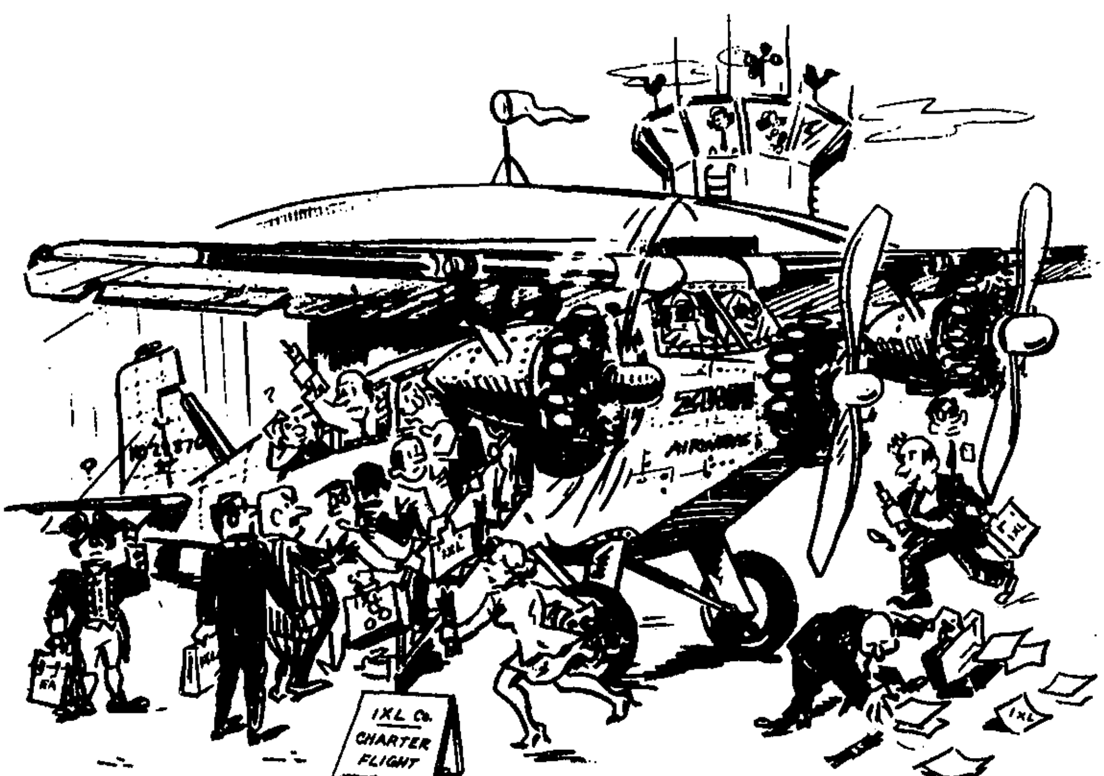
- Bid times

Is the direct manufacturing labor estimate fair and reasonable? Make your cost recommendation to the contracting officer.

Subsection III-E. EVALUATING "OTHER COSTS" ESTIMATES

You should evaluate labor and material costs charged to "other costs" in the same manner as you evaluate costs charged to direct manufacturing and engineering labor and direct material. In the previsit phase, accumulate and examine as much cost data as you can get and develop an action plan for your onsite phase. In the onsite phase, gather and analyze more cost data, ask contractor personnel pertinent questions, and examine plant efficiency. In the postvisit phase, review your findings and work toward your cost recommendations.

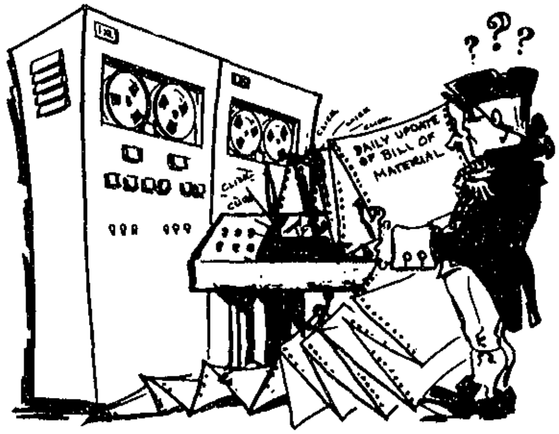
Such costs as travel and computer-use expenses, which are not labor or material costs, should be supported by cost data made available



PROPOSED COSTS FOR CONTRACT TRAVEL MUST BE CAREFULLY ANALYZED TO BE SURE THAT THEY ARE NOT EXCESSIVE.

during either the previsit or onsite phase. Onsite observations will help little here, because overall plant efficiency has little bearing on these costs.

For proposed trips by contractor personnel, examine the contractor's backup data to see how many trips are proposed, to where, and how many are to go. The data also should tell why the trips are necessary. Consult with other members of the cost analysis team, as necessary, to determine whether the trips are justified and how many contractor employees should be allowed to travel.



QUESTION EXCESSIVE COMPUTER RUNS.

For computer-use costs, look at the amount of work the contractor proposes to do by computer. Excessive computer use is costly. Government experts may be able to tell you whether the contractor is relying too heavily on his computers.

Many items charged to "other costs" probably could have been charged to other DD For 633 line items. Consider special tooling. To develop a special tool, engineers must design the tool, draftsmen must draw the tool, and direct manufacturing laborers must fabricate the tool. A contractor could charge design and drafting costs to the direct engineering labor element and fabrication costs to the direct manufacturing labor element. On the other hand, he could charge special tooling costs to the "other costs" element. A contractor may even charge special tooling to manufacturing overhead. As you can see, when you evaluate "other costs," you should keep a sharp eye for double-charges.

If the contractor proposes special test equipment, you should ensure that:

- It is not charged to both an overhead account and "other costs"
- It has not already been paid for by prior contract work.
- It is unlikely to be used on other contracts
- Government-furnished equipment cannot be made available.

Subsection III-F. A REVIEW OF BASIC PRINCIPLES

Perhaps the most important principle in direct cost analysis is this: A manufacturer's efficiency--or lack of efficiency--is rooted in the practices of his total labor force. A one-time gross inefficiency involving a single worker is less important than a few minutes of inefficiency repeated many times by many workers.

There are thousands of examples of the value of this principle, Contrast these two cases:

(1) You find a worker produces nothing yet is proposed to work under direct charge to your contract. Your finding, an extreme case, might save $10,000 in wages plus, say, $10,000 in indirect costs plus profit over the course of a year. Total savings: about $20,000.

(2) You make a series of observations at a module assembly area in a contractor's plant. You find that the average worker waits for 20 minutes a day for parts to be restocked. (Further, you find that modules are checked one by one on testers that can test up to ten at a time, amounting to a total of 30 man-hours wasted per day.

Looking even further, you find only one time clock. . Employees, wishing to leave at quitting time, stop work early to line up at the timeclock. The average wait to clock out is 10 minutes per day per worker. There are about 100 assembly workers proposed for your contract for the first 6 months.

Add up the wasted time: Each worker loses 20 minutes a day waiting on parts and 10 minutes a day lining up to punch out. Thirty minutes per worker per day times 100 workers equals 3000 man-minutes, or 50 man-hours lost from productive work each day. Add in the 30 man-hours per day for inefficient use of testers, and you find 80 man-hours wasted per day. In 6 months, 5 man-years of "effort" will be lost. Total savings possible sible: about $100,000.

A second basic principle of direct cost analysis is this: Not all losses in productive labor time or direct material can be avoided. Discerning avoidable and unavoidable delays and material waste is essential to a fair analysis of direct cost estimates.

Making this distinction can be difficult, as we show in the following two examples.

(1) A contractor says a standard practice of his is to add 3 percent to his direct manufacturing labor estimate to account for periodic work stoppages resulting from electrical failures, machine breakdowns, and union-required safety inspections. He supports these claims with historical data showing that these delays, in fact, have consumed about 60 hours per year, or 3 percent of each worker's time. You check with DCAA and find that overhead does not already account for the delays. You are satisfied that the delays are unavoidable.

(2) The same contractor says that it is also his standard management practice to purchase one size of aluminum plate stock for fabricating all chassis frames, unfortunately, he says, with your product he can cut only one chassis per plate, resulting in 36 percent scrap. He shows you actual purchase records to support his claim. Despite his history, the contractor need not stick with one stock size, "standard management practice" notwithstanding. You should recommend a reduction in the proposed high scrap rate.

A third basic principle is that authorized Government representatives have the legal right to all cost data used by the contractor, no matter whether or not he considers the data to be "proprietary information." Besides having this right, you, as a technical evaluator, have the obligation to obtain the data you need. Often, you will not get needed information unless you ask for it.

The difference between data and no data is often the difference between fair estimates and overestimates. Consider these two contrasting cases:

(1) You are analyzing a proposal for specially designed, high-capacity, high-pressure pumps being obtained "sole-source." The proposed price is $36,000 per pump, of which $15,000 is direct cost. The Government plans to buy 100 pumps, for a total price of $3.6 million. Cost data included in the proposal lists $250,000 under "Test and Test Support--Direct Labor." You think that $2500 per pump ($250,000 divided by 100) may be too much. You visit the plant and observe about 25 technicians busily working in the test bay. You ask the test supervisor what they all do, but his response leaves you confused. You see no glaring inefficiencies. In summary, unless you can get more backup data, you cannot analyze the proposed cost.

(2) Same contractor, same pumps, same $250,000 in test. This time, you do some homework before visiting the plant. You ask the contracting officer to get a detailed breakdown of the quality control labor force by pay grade (such as, senior technician or junior mechanical test engineer) and by hours per level of labor per test. When you arrive at the plant,

the data listings are given to you. Most labor is in the "senior" category, you observe. You ask the Government project engineer with you to brief you on test requirements.

Next day, you both visit the test bay and ask the test supervisor to give you a 5-minute overview of the test flow. You ask a few pertinent questions: About how long does it take to test one of our pumps? Does that include both functional (performance) and environmental (shock and vibration) tests? What's the breakdown for each test, individually? Who gets involved in which tests? Later that day you compare data, observations, and answers to questions. You find that senior personnel initially are required for functional tests but not for all tests, as was proposed. You and the project engineer develop your own estimate: $1000 for test of each pump. Later, your findings are presented in negotiating sessions. You have the data to support your position. The Government saves $140,000 in direct costs and about $340,000 in total price.

Another principle you should have is to be professional in your work. Your common sense in detecting inefficiency must be followed by facts if you hope to correct inefficiency.

Being "professional" means being able to develop your own direct cost estimates. Two important reasons for being able to do this are:

- It ensures that the Government's position on direct costs is based on evidence.

- It provides the contracting officer with flexibility at the negotiation table.

The latter point is of great significance. Your contracting officer is interested in anything that will help him to be flexible, to weigh the facts, to listen to the contractor, to act with good faith, and to maintain the initiative at the negotiation table.*

Being professional in your work does *not* mean you have to be an indistrial engineer before you can be an effective member of the cost analysis team. It means that you understand your goals, your current capabilities, and your limitations. You know when to get help and the importance of always being willing to learn. Then you can do your job well.

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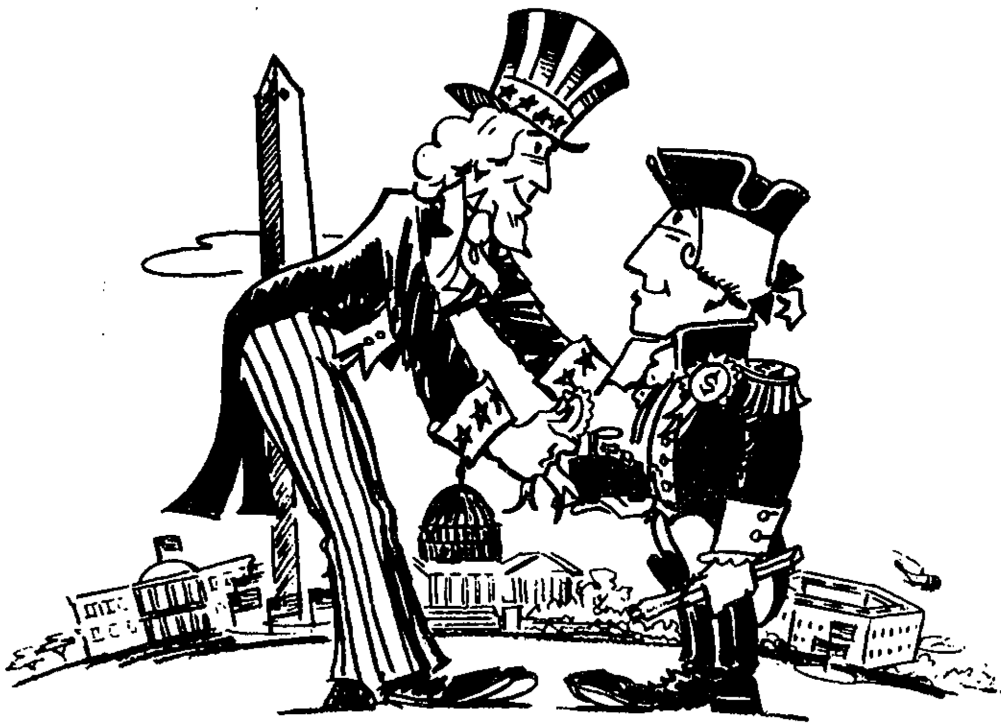
*See *The Art of Negotiation* by Gordon Rule (Director, Procurement Control and Clearance Division, NAVMAT). You are encouraged to study sections V-A and V-B of that document. These sections contain long-proved cardinal rules for those who participate in negotiation.



YOUR COUNTRY THANKS YOU, "SIR", FOR A JOB WELL DONE.

SELECTED BIBLIOGRAPHY

Andress, Frank J. *The Learning Curve as a Production Tool.* January February 1954. The Harvard Business Review.

*Armbrust, John S. *A Cost Function Based on Learning Curve Theory.* June 1970. Air Force Institute of Technology.

*Asher, Harold. *Cost-Quantity Relationships in the Airframe Industry.* July 1956. The Rand Corporation.

†ASPM No. 1 (*Armed Services Procurement Regulation Manual for Contract Pricing*). February 1969. Commerce Clearing House, Inc.

Baloff, Nicholas. *The Learning Curve - Some Controversial Issues.* 1966. The Journal of Industrial Economics.

——. *Startup Management.* November 1970. IEEE Transactions on Engineering Management.

Barnes, Ralph M. *Motion and Time Study.* Third Edition 1950. John Wiley & Sons Book Company.

*Barrett, Charles Francis. *An Empirical Analysis of Learning Curves.* November 1970. Air Force Institute of Technology.

*Batchelder, C. H., Boren, H. E. Jr., Campbell, N. C. *An Introduction to Equipment Cost Estimating.* December 1969. The Rand Corporation.

Biron, Leo J. *Decision-Making by the Numbers.* October 1969. The Tool and Manufacturing Engineer.

Bolz, Roger W. *Production Processes: The Producibility Handbook.* 1963. Penton Publishing Company, Cleveland, Ohio.

*Brewer, Glenn M. *The Learning Curve in the Air Frame Industry.* August 1965. Air Force Institute of Technology.

*Available at National Technical Information Service
†Special Recommendation

*Brockman, William F. et al. *Investigation of Learning Curve and Cost Estimation Methods for Cargo Aircraft.* December 1967. Air Force Institute of Technology.

Carson, Gordon B. *Production Handbook.* Second Edition 1959. Ronald Press Company.

Cochran, E. B. *Planning Production Costs: Using the Improvement Curve.* 1969. Chandler Publications.

*Colnsuonno, Vincent. *An Analysis of Progress Curve Conceptual Advances and Progress Curve Uses, Since 1956.* September 1967. Air Force Institute of Technology.

Conway, R. W. and Schultz, A. *The Manufacturing Progress Function.* Department of Industrial and Engineering Administration. Cornell University, Ithaca, New York.

*Dahlhaus, Frank J. et al. *Learning Curve Methodology for Cost Analysts.* Army Materiel Command. October 1967.

†Dickey, Robert I. *Accountants' Cost Handbook.* Second Edition 1967. Ronald Press Company.

*Early, L. B., Barro, S. M., Margolis, M. A. *Procedures for Estimating Electronic Equipment Costs.* May 1963. The Rand Corporation.

*Eisemann, Doris M. *The Progress-Curve Computer.* September 1958. The Rand Corporation.

*Eliel, F. *Compound Progress Curves - An Approximation to Multi-Element Learning C --- etc.* Aerospace Corporation. June 1965.

Frederic, Brad. *Learning Curve Analysis.* October 1962. TEMPO, General Electric Company, Santa Barbara, California.

†Gallagher, Paul F. *Project Estimating by Engineering Methods.* 1965. Hayden Book Company.

*Graver, Charles. *The Use of Classical Statistics in Deriving and Evaluating CER's.* October 1966. Operations Research Society of America, Durham, North Carolina.

Greene, J. H. *Production and Inventory Control Handbook.* 1970. McGraw-Hill Book Company.

*Available at National Technical Information Service
†Special Recommendation

Hancock, Walton M. *The Prediction of Learning Rates for Manual Operations.* January 1967. Journal of Industrial Engineering.

*Harris, Robert A. *Pamper: Practical Application of Mid-Points for Exponential Regression.* U. S. Army Missile Command Redstone Arsenal, Alabama. January 4, 1965.

†Hartmeyer, Fred C. *Electronics Industry Cost Estimating Data.* 1964. The Ronald Press Company.

*Hartung, Walter G. *Cost Estimate Errors Resulting from the Use of Learning Curve Methods.* Electronic Systems Division. L. G. Hanscom Field, Mass. August 1969.

Hirschmann, Winfred B. *Profit From the Learning Curve.* January - February 1964. The Harvard Business Review.

Ireson, William Grant. *Handbook of Industrial Engineering and Management.* 1956. Prentice-Hall.

*James, Paul Meyer. *Deriviation and Application of Unit Cost Expressions Perturbed.* Naval Air Systems Command. 1968.

*——. *Analysis of the Turbulent Regime of the Progress Curve When New L --- etc.* Naval Air Systems Command. 1968.

Karsch, Arthur O. *A Least Squares Comparison for Learning Curve and Sizing Slope Problems.* February 1971. Directorate of Advanced System Cost. Wright Patterson AFB, Ohio.

*Kelley, Robert W. *Value Engineering and Experience Curve Predictions.* September 10, 1965. Procurement and Production Directorate, United States Army Missile Command.

*Large, J. P. *An Introduction to Equipment Cost Estimating.* January 1968. The Rand Corporation.

*Levenson, G. S. et al. *Cost-Estimating Relationships for Aircraft Airframes.* May 1966. The Rand Corporation.

Lockheed Missile & Space Company. *Value Engineering Handbook* - Economic Evaluation, Cost Analysis and Time Standards.

*Logistics Management Institute. *Multi-Year Procurement and Learning Curve Effects.* Washington, D. C. October 1967.

*Available at National Technical Information Service
†Special recommendation

*Margolis, M. A. *Use of Cost Estimating Relationships in the Airframe Industry*. October 1966. The Rand Corporation.

Martinson, Otto B. Jr. *A Standard Classification System for Indirect Costs of Defense Contractors in the Aircraft Industry*. 1969. Department of Economics, U. S. Air Force Academy.

†Maynard, H. B. *Industrial Engineering Handbook*. Third Edition 1971. McGraw-Hill Book Company.

McNeill, Thomas F., Clark, Donald S. *Cost Estimating and Contract Pricing*. American Elsevier Publishing Company, Inc. New York. 1966.

Moore, Franklin G. and Jablonski, Ronald. *Production Control*. 1969. McGraw-Hill Book Company.

Morrow, Robert Lee. *Time Study and Motion Economy*. 1946. The Ronald Press Company.

Mosbaek, Ernest J. *Handbook for Applying Expedient Unit Cost Estimating*. January 1959. TEMPO, General Electric Company, Santa Barbara, California.

†The MTM Association for Standards and Research, Fair Lawn, New Jersey. MTM Research Studies Report Number 112, Learning Curve Research in Short Cycle Operations. Phase 1: Laboratory Experiments, May 1963.

†——. MTM Research Studies Report Number 113A, Learning Curve Research on Manual Operations. Phase 2: Industrial Studies. Revised Edition, 1969.

Mundell, M. E. *Motion and Time Study*. Prentice-Hall. 1970.

Niebel, Benjamin W. *Motion and Time Study*. 1967. Richard D. Irwin, Inc. Homewood, Illinois.

*Noah, J. W. and Smith, R. W. *Cost-Quantity Calculator*. January 1962. The Rand Corporation.

†Nordhoff, W. A. *Machine-Shop Estimating*. McGraw-Hill Book Company. Second Edition 1960.

*Novick, David. *Use of the Learning Curve*. November 1951. The Rand Corporation.

*Available at National Technical Information Service
†Special recommendation

*Orsini, Joseph A. *An Analysis of Theoretical and Empirical Advances in Learning Curve Concepts Since 1966.* March 1970. Air Force Institute of Technology.

Patton, Wiley F. *Predicting Production Costs with Learning Curves.* November 1969. Defense Industry Bulletin.

Pritzker, Robert A. and Gring, Robert A. *Modern Approaches to Production and Control.* American Mangement Association, Inc. 1960.

*Rand Corporation, Santa Monica, California. April 1970. *Learning-Curve Tables: Volume 1 55-69 Percent Slopes.*

*——. April 1970. *Learning-Curve Tables: Volume II 70-85 Percent Slopes.*

*——. April 1970. *Learning-Curve Tables: Volume III 86-99 Percent Slopes.*

†Rule, Gordon M. *The Art of Negotiation.* 1962. Washington, D. C.

Schiff, Michael and McFarland, Walter B. and Land, Theodore. *Cost Accounting.* The Ronald Press Company. 1953.

Schlatter, W. J. and C. F. *Cost Accounting.* Second Edition 1957. Wiley Publications in Accounting.

Stegemerten, G. J., Maynard, Harold B. and Lowry, Stewart M. *Time and Motion Study and Formulas for Wage Incentives.* Third Edition 1940. McGraw-Hill Book Company.

Tucker, Spencer A. *Cost-Estimating and Pricing with Machine-Hour Rates.* Prentice-Hall, Inc. 1962.

Vitro Laboratories. Technical Note No. 01563-01.1. *Final Report and User Guide for NAVSEC 6276C F-Cognizance Production Cost Estimating.* 12 March 1971.

*Waggoner, Larry P. *Army Materiel Experience Curve Guideline.* July 1971. Army Materiel Systems Analysis Agency.

†Wilson, Frank W. *Manufacturing Planning and Estimating Handbook.* 1963. McGraw-Hill Book Company.

*Available at National Technical Information Service
†Special recommendation

———. *Numerical Control in Manufacturing*. 1963. McGraw-Hill Book Company.

Wright, Howard W. *Accounting for Defense Contracts*. 1962. Prentice-Hall Inc.

Wright, T. P. *Factors Affecting the Cost in Airplanes*. February 1936. Journal of the Aeronautical Sciences.

Young, Samuel L. *Misapplications of the Learning Curve Concept.* August 1966. Journal of Industrial Engineering.

U. S. Army Materiel Command. Comptroller Headquarters. *Profile of Cost Analysis in AMC (Final Report)*. Washington, D. C. 20315. December 10, 1969.

†*U. S. Army Missile Command Redstone Arsenal, Alabama. *Alpha and Omega and the Experience Curve*. April 12, 1965.

*———. *The Experience Curve - Volume I 67%-84%.* September 1962.

*———. *The Experience Curve - Volume II 85%-99%.* September 1962.

*———. *Tamper-Tables for Approximation of Midpoints for Exponential Regression.* December 1965.

*———. *Development Independent Cost Estimate (DICE).* 1 April 1964.

U.S. Comptroller General. *Report on the Feasibility of Applying Uniform Cost-Accounting Standards to Negotiated Defense Contracts.* January 1970.

U. S. Congress. *Government Procurement and Contracting.* Hearings before a Sub-Committee of the Committee on Government Operations House of Representatives Ninety-First Congress First Session on H.R. 474, May 5, 6, 13 and 14, 1969.

U. S. Department of Defense. Office of Assistant Secretary (SA). *Results of Department of Defense Cost Research Survey.* March 1970.

———. *Procurement Training Handbook.* 1968 Edition with Revisions.

———. *Armed Services Procurement Regulation.* 1696 Edition with Revisions.

———. *Casebook Life Cycle Costing in Equipment Procurement.* July 1970.

*Available at National Technical Information Service
†Special recommendation

———. *Cost Information Reports (CIR)* for Aircraft, Missile, and Space Systems. Budget Bureau #22-R260. April 21, 1966.

U. S. General Accounting Office. *Application of "Should Cost" Concepts in Reviews of Contractors' Operations*. 1971.

———. *Acquisition of Major Weapons Systems*. 1971.

U. S. Military Operations Subcommittee of the Committee on Government Operations. *Government Procurement and Contracting (Part 5)*. May 6, 1969.

U. S. Naval Air Technical Services Facility. *Contractor's Guide to Technical Manual Repetition Analysis*. June 1969.

———. *Government Manager's Guide:* (To Technical Manual Cost Effectiveness). June 1969.

———. Government Manager's Technical Manual *Cost Analysis Guide*. January 1970.

U. S. Naval Electronic System Command. *Cost Estimating Data and User Guidance*. Volume I of VI. 1 March 1972.

U. S. Naval Ordnance System Command (NAVORD). *Guide for ACO's Review of Quotations*. "Contract Administrative Offices". April 10, 1964.

GLOSSARY

ACO--Administrative Contracting Officer--Official responsible for administering any resulting contract.

Actual Cost--The sum of the allowable direct and indirect costs (allocable) incurred as a result of producing a part, product, or service.

Actual Time--The time taken by a workman to complete a task or an element of a task.

Additive Factor--Factor used to increase the basic make time of an item or component--usually expressed as a percentage and includes such factors as shrinkage, PF&D, and realization.

ADP--Automatic Data Processing--Computer used to accumulate, calculate and report the financial and operating status of a company and its contracts.

Allocated Min-Max--A method based on historical costs for estimating the cost of indirect materials. Two percentages are developed which define a range of allowable and auditable indirect material cost.

Allowance--A time increment included in the standard time for an operation to compensate the workman for production lost due to fatigue and normally expected interruptions, such as personal and unavoidable delays. It is usually applied as a percentage of the normal or leveled time.

Allowed Time--The leveled time plus allowances for personal needs, fatigue, and unavoidable delays (see Standard Time). Special allowances can also be included in the allowed time of an operation.

Assembly--Two or more parts or subassemblies joined together to form a complete unit, structure, or other article.

Attrition--The lost of a resource due to natural causes in the normal course of events such as turnover of employees or spoilage and obsolescence of material.

Automaticity--The ability to perform hand, arm, leg, or body motions or motion patterns without apparent mental direction, as a result of practice.

Average Earned Rate--The total earnings of an individual or group of individuals for a period divided by the number of man-hours worked during the period. Total earnings include all of the components which are a function of pay per hour such as base rate earnings, shift differentials, incentive earnings, overtime premiums, and the like, but not profit-sharing bonuses, Christmas bonuses or other bonuses that are not a function of pay per hour.

Average Earnings--The total earnings of an individual or group of individuals during a specified period divided by the number of man-hours, man-days, man-weeks, man-pay periods, or any similar measure of the time elapsed during the specified period.

Average Elemental Time--The sum of all the unleveled, individual actual time recorded for an element divided by the number of unleveled, individual actual times.

Average Time--The arithmetical average of all the actual times, or of all except the abnormal times, taken by a workman to complete a task or an element of a task.

Avoidable Delay--Any time during an assigned work period which is within the control of the workman and which he uses for idling or for doing things unnecessary to the performance of the operation. Such time does not include allowance for personal requirements, fatigue, and unavoidable delays.

Balanced Line--A series of progressive related operations with approximately equal standard times for each, arranged so that work flows at a desired steady rate from one operation to the next.

Balancing Delay--The delay which occurs when one body member performs its work faster than another body member because of different motions, due to the requirements of the layout or the required sequence of motions, and therefore, must wait for the slower member or must work more slowly so as to finish its work simultaneously with the slower body member.

Bank--A planned accumulation of work-in-process to permit reasonable fluctuations in performance times of coordinated or associated operations.

Base Pay--See Base Wage Rate. The product of a workman's base wage rate and the time he worked during a pay period, when expressed in the proper measurement units.

Base Wage Rate--The amount of pay per hour, or other unit of time, established to compensate the workman for the requirements and conditions associated with a job.

Bid Hours--The total number of labor hours proposed by the contractor including all allowances and additive factors.

Bill of Material--A document produced from product specifications which breaks down one level of the product into its sublevels with corresponding quantities.

Bin Stock--See Line Stock.

Bonus--The portion of wages, in excess of base wages and overtime earnings, derived from incentive-plan payments. Synonym: premium.

Bonus Plan--(See Financial-Incentive Plan)

Bottom Line--Total contract price, or bottom line of DD Form 633.

Burden--See Overhead.

Catalog Price--Price quoted for parts and equipment which are manufactured to inventory and which (price) may be quoted independently of a specific contract.

CDRL--Contract Data Requirements List--A contractual document which specifies end item documents and reports (see DD Form 1423).

CER--Cost Estimating Relationship--The curve of a cost function which relates the cost of a product to some measurable characteristic of its manufacture and from which extrapolations and interpolations may be extracted for estimating purposes.

Commercial Item--An item sold regularly to the general public by a Government contractor.

Complexity Factor--A judgment/experience factor to take care of the degree of unknowns and design growth anticipated within a component or project.

Contingency--An activity which will probably occur but the cost of which is unknown.

Convergence Point--The value (on the X-axis) where the experience curve crosses the horizontal line representing the labor standard. The point in time (unit number) when workers, on a learning curve attain standard performance.

Cosmetic Finish--The "finishing" of fabricated or assembled parts by performing metal plating, painting, anodizing, or other operations which affect the appearance of the parts' external surfaces.

Cost Accounting--A system of methods and records which organizes and displays the actual costs associated with a given production contract.

Cost Analysis--The review and evaluation of a contractor's cost or pricing data and of the judgmental factors applied in projecting from the data to the estimated costs, in order to form an opinion on the degree to which the contractor's proposed costs represent what performance of the contract should cost, assuming reasonable economy and efficiency. It includes the appropriate verification of cost data, the evaluation of specific elements of costs, and the projection of these data to determine the effect on prices (RE: ASPR 3-807.2).

Cost Center--Any subdivision of an organization comprised of workmen, equipment areas, activities, or combination of these that is established for the purpose of assigning or allocating costs. Cost centers are also used as a base for performance standards. Synonym: burden center, cost pool.

Cost Data--Recorded information on costs previously incurred in any place of a business.

Cumulative Average--The average expenditure per unit for all units produced through any given unit.

Cumulative Total--The total expenditure for all units produced through any given unit.

Cutting Speed--The relative velocity, usually expressed in feet per minute, between a cutting tool and the surface of the material from which it is removing stock. Synonym: cutting rate.

Data Item--A document or report required by contract (see CDRL).

Day Rate--Rate of compensation for day work as differentiated from incentive work. Usually expressed in terms of money paid per period of time.

Day Work--Work for which the hourly or daily compensation is not directly dependent upon the quantity of production, as is the case in incentive work.

DCAA--Defense Contract Audit Agency.

DCAS--Defense Contract Administration Service, reporting to Defense Services Administration.

Delay--A period during which conditions (except those which intentionally change the physical or chemical characteristics of an object) do not permit or require immediate performance of the next planned action.

Delay Allowance--A time increment included in a time standard to allow for predictable contingencies and minor delays beyond the control of the workman.

Depletion--A lessening of the value of an asset due to a decrease in the quantity available. It is similar to depreciation except that it refers to such natural resources as coal, oil, and timber in forests.

Direct Cost--Labor and material charged and traceable to an end product.

Direct Engineering--Engineering effort directly traceable to the design, manufacture, or control of specific end products.

Direct Labor Standard--A specified output or a time allowance established for a direct-labor operation.

Direct Manufacturing Labor--Work which alters the composition, condition, conformation, or construction of the product; the cost of which can be identified with and assessed against a particular part, product, or group of parts or products accurately and without undue effort and expense; colloquially called "direct labor."

Direct Material--All material that enters into and becomes part of the finished product (including waste), the cost of which can be identified with and assessed against a particular part, product, or group of parts or products accurately and without undue effort and expense.

Distribution Costs--Costs incurred in promoting sales and in moving the product to the customer.

Double-Charge--A cost incurred once by a contractor but charged to the Government twice.

Downtime--A period of time that is usually equal to or greater than a specified minimum during which an operation is halted due to a lack of materials, a machinery breakdown, or the like.

DSA--Defense Services Administration.

Earned Hours--The time in standard hours credited to a workman or group of workmen as a result of their completion of a given task or group of tasks.

Economic Lot Size--That number of units of material or a manufactured item that can be purchased or produced within the lowest unit-cost range. Its determination involves reconciling the decreasing trend in preparation unit costs and the increasing trend in unit costs of storage, interest, insurance, depreciation, and other costs incident to ownership, as the size of the lot is increased.

ECP--Engineering Change Proposal--Request for authorization to make a change in configuration (design, documentation, support, etc.)

Efficiency Factor--The ratio of standard performance time to actual performance time, usually expressed as a percentage.

End Product--Products deliverable to the customer as specified in the contract. Frequently referred to as "contractor end item".

Experience Curve--A curve plotted in a cortesian (X-Y) coordinate system whose axes are units of time and production quantity. The curve depicts the relationship between quantity and time such that (1) as the quantity increases the average production time for that quantity decreases at an exponential rate, or (2) as the quantity increases the unit production time decreases exponentially.

Fair Day's Work--The amount of work that can be produced during a working day by a qualified individual with average skill who follows a prescribed method, works under specified conditions, and exerts average effort.

Fair and Reasonable Cost--A cost is reasonable if, in its nature or amount, it does not exceed that which would be incurred by an ordinarily prudent person in the conduct of competitive business.

FAT--Factory Acceptance Test--Contractor performed final inspection and test on items of completed product before submission to the Government for acceptance.

Fatigue--A physical and/or mental weariness, real or imaginary, existing in a person, adversely affecting the ability to perform work.

Fatigue Allowance--Time included in the production standard to allow for decreases or losses in production which might be attributed to fatigue. (Usually applied as a percentage of the leveled, normal, or adjusted time.)

Finance Costs--The cost of supplying money or credit necessary to conduct the operations of the business--an overhead cost.

First Piece Time--The time required to produce the first of a number of identical units including all necessary setup and make-ready time. See Prototype factor and Unit One.

Fixed Costs--Costs which must be paid regardless of the quantity of products produced.

G & A Costs--General and Administrative Costs--An overhead cost category for accumulation of such costs as personnel department, accounting, purchasing.

Gantt Chart--A graphic representation on a time scale of the current relationship between actual and planned performance.

GAO--General Accounting Office.

Group Incentive--Any financial-incentive plan under which the output of workmen performing the same, related, or interdependent operations is pooled and their earnings resulting from production above the established standard are distributed to the members of the group according to some predetermined plan.

Guaranteed Annual Wage--A minimum amount of money which an employee is assured he will receive during a given year.

Guaranteed Time Standard--An established, expected performance level which management assures will not be changed regardless of workmen's earnings unless there is a significant change in quality, requirements, method, materials, tools, layout, equipment, feeds, speeds design, or working conditions.

Guaranteed Wage Rate--The assured minimum amount of compensation per hour, or other unit of time, paid under a financial-incentive plan even though the workman fails to reach the established standard or specified level of performance.

Hardware--Any manufactured equipment, system or component thereof, representing the product(s) of a production contract.

Historical Cost System--Accumulates actual costs after operations have taken place.

Idle Time--A time interval during which either the workman, the equipment, or both do not perform useful work.

Incentive--Any factor which motivates a workman to maintain or exceed an established standard of performance--may be financial or nonfinancial in nature.

Incentive Earnings--The amount of money paid to a workman in excess of the guaranteed hourly rate for performance at or above the established standard.

Incentive Performance--The execution of work by a qualified individual following a specified method in such a way that his average output during a specified period of time equals or exceeds the established standard level of output.

Incentive Rate--The hourly wage rate used for incentive calculations.

Indirect Cost--Costs necessary in manufacturing which cannot be readily identified with or charged to a particular part, product, or group of parts or products.

Indirect Expense--See Indirect Cost.

Indirect Labor--Work which is performed rendering services necessary to production, the cost of which cannot be assessed against any part, product, or group of parts or products accurately or without undue effort and expense.

Indirect Manufacturing Expense--See Overhead.

Indirect Material--Material consumed in the process of production or manufacture that does not become a part of the finished product and/or cannot be readily identified with or charged to a particular part, product, or group of parts or products.

Industrial Engineering--The art and science of utilizing and coordinating men, equipment, and materials to attain a desired quantity and quality of output at a specified time and at an optimum cost. This may include gathering, analyzing, and acting upon facts pertaining to building and facilities, layouts, personnel organization, operating procedures, methods, processes, schedules, time standards, wage rates, wage-payment plans, costs, and systems for controlling the quality and quantity of goods and services.

Interdivisional Transfer--The transfer of material under common control between separately managed divisions of the same company.

Interference Time--A period of time during which one or more machines are not operating because the workman or workmen assigned to operate them are busy operating other machines in their assignment or are performing necessary duties related to operating such other machines such as making repairs, cleaning the machines, or inspecting completed work.

Internal Review--A recommended procedure to be done by the contractor in order to audit and update his own estimating or quoting system.

Inventory--All of the materials, parts, supplies, expense tools, and in-process or finished products recorded on the books by an organization and kept in its storerooms, warehouses, or plants.

Job Lot--A relatively small number of a specific type of part or product that is produced at one time. The part or product may be a standard item that has been and will again be produced, or it may be a special item destined for a specific customer who has not ordered it before and may not order it again.

Job-Lot Production--The manufacturing of parts or products to customer or stock orders in small quantities.

Job Order Cost System--Direct and overhead cost data are accumulated by each contract or order.

Job Shop--A manufacturing enterprise devoted to producing special or custommade parts or products usually in small quantities for specific customers.

Job Standardization--The establishment of a prescribed method for performing an operation or procedure and the specifying of its minimum requirements.

Labor Cost--That part of the cost of goods, services, and the like attributable to wages. It commonly refers only to direct workmen, but may include indirect workmen as well.

Labor Productivity--The rate of output of a workman or group of workmen per unit of time, usually compared to an established standard or expected rate of output (see Efficiency).

Labor Standard--See Standard Time.

Level of Effort--A bidding (estimating) technique which specifies the amount of labor to be expended on the basis of a given number of people working for a given time.

Leveled Time--The average time adjusted to account for differences in skill, effort, conditions, and consistency between workmen and the factors surrounding an operation (see Normal Time).

Line Production--A method of plant layout in which the machines and other equipment required, regardless of the operations they perform, are arranged in the order in which they are used in the process (layout by product).

Line Stock--Parts or components (for example, screws, washers, solder, common resistors, etc.) which are physically identifiable with the product, but which are of very low value, and therefore, do not warrant the usual item-by-item costing techniques.

Machine Attention Time--That portion of a machining operation during which the workman performs no physical work yet must watch the progress of the work and be available to make necessary adjustments, initiate subsequent steps or stages of the operation at the proper time, and the like.

Machine Controlled Time--That part of a work cycle that is entirely controlled by a machine and, therefore, is not influenced by the skill or effort of the workman.

Machine Element--A work-cycle subdivision that is distinct, describable, and measurable, the time for which is entirely controlled by a machine, and, therefore, not influenced by the skill or effort of the workman.

Machine Idle Time--That portion of a regular working period during which a machine that is capable of operating is not being used (see Downtime).

Make-or-Buy--Analysis performed by a contractor to determine whether an item should be made "in-house" or purchased from an outside supplier.

Man-hour--A unit for measuring work. It is equivalent to one man working at normal pace for 60 minutes, two men working at normal pace for 30 minutes, or some similar combination of men working at normal pace for a period of time--forms the basis for man-day, month, and year.

Manual Element--A distinct, describable, and measurable subdivision of a work cycle or operation performed by one or more human motions that are not controlled by process or machine.

Manufacturing Engineering--Preproduction planning and operation analysis applied to specific projects. Other similar functions include sustaining (on-going) engineering, production engineering, and production planning.

Manufacturing Outline--See Process Sheet.

Manufacturing Overhead--A form of indirect costs--accumulated manufacturing costs prorated over all products in process, generally as a percent of direct labor and/or material.

Measured Daywork--The establishment of standard or allowed times for operations without providing the opportunity for incentive earnings.

Methods Engineering--The technique that subjects each operation of a given piece of work to close analysis in order to eliminate every unnecessary element or operation and in order to approach the quickest and best method of performing each necessary element or operation. It includes the improvement and standardization of methods, equipment, and working conditions; operator training; the determination of standard times; and occasionally devising and administering various incentive plans.

Methods-Time Measurement--A system for development predetermined leveled times for human body motions (see Predetermined Standards).

Minimum Buy--The purchase of material in standard bulk quantities even though the contract requirement is less than the standard quantity. This is done when price does not decrease proportionately for quantities less than the standard quantity.

Motion-Time Analysis--A system of predetermined motion-time standards used for describing and recording an operation in terms of its motions. The value of each motion is predetermined both as to utility and time allowance (abbreviated as MTA).

Multiyear Buy--A procurement of more units of product than can be funded by the Government in a single year. The total purchase is divided into annual segments which are negotiated at one time. Under multiyear conditions, the Government pays lower unit prices due to larger buys; however the contractor is protected from annual cancellations through clauses in the contract.

NC--Numerical Control--Tape controlled machine operation which provides high repeatability for multiple process steps.

Negotiated Contract--Method of arriving at understanding and agreement on all terms and conditions of the contract (see ASPM No. 1 Ch. 13).

Nominal Cost Center--Grouping of costs for convenience only--no particular activity conducted. Frequently associated with indirect overhead items such as payroll and other taxes (Indirect Cost Center).

Nonrecurring--A descriptive term applied to a type of work, operation, part, or the like that does not recur frequently or in any reasonable regular sequence (also Nonrepetitive).

Nonstandard Parts--Parts for which no military specification has been written documenting the parts' physical nature, price and source.

Normal Pace--The work rate usually used by workmen performing under capable supervision but without the stimulus of an incentive-wage-payment plan. This pace can easily be maintained day in and day out without undue physical or mental fatigue and is characterized by the fairly steady exertion of reasonable effort.

Normal Time--The time required by a qualified workman, working at a pace which is ordinarily used by workmen when capably supervised to complete an element, cycle, or operation when following the prescribed method.

Obsolescence--A decrease in the value of an asset or resources brought about by the development of new and more economic methods, processes, and/or machinery or by the change in design of the end product.

Operation--The intentional changing of an object in any of its physical or chemical characteristics; the assembly or disassembly of parts or objects; the preparation of an object for another operation, transportation, inspection, or storage; planning, calculating, or the giving or receiving of information.

Output Standard--Specifies the number of items or amount of services that should be produced in a specific amount of time by a specific method.

Overage Factor--See Shrinkage.

Overhead--Fixed and semivariable costs which are charged directly to overall operation and prorated over all contracts.

PCO--Procurement Contracting Officer--Contracting officer assigned responsibility for making the procurement.

Personal Allowance--Time included in the production standard to permit the workman to attend the personal necessities such as obtaining drinks of water, making trips to the rest room, and the like. Usually applied as a percentage of the leveled, normal, or adjusted time.

Predetermined Cost System--Costs are computed in advance of expenditures.

Predetermined Standards--Measurements of the time taken to perform basic bodily motions (reaching, grasping, releasing) (also called Predetermined-Level Time Techniques).

Premium Pay--Overtime and/or night shift pay generally at a higher rate than for regular hours.

Price--Total contract dollars including direct cost, overhead, profit (see DD Form 633; colloquial-bottom line).

Price Analysis--The process of examining and evaluating a prospective price without evaluation of the separate cost elements and proposed profit of the individual prospective supplier whose price is being evaluated (RE: ASPR 3-807.2).

Price Break--A decrease in the unit price of an item offered by a vendor to those purchasing the item in large quantities.

Process Cost System--Total costs for producing a type of unit and the number produced are determined for regular accounting periods and an average unit cost based on that data is determined.

Process Sheet-A document, originating in manufacturing engineering and sent to the production floor, which describes and illustrates methods and tools to be used in fabricating or assembling specific parts or subassemblies.

Production Center--The area containing the machine or machines operated by a workman or workmen as well as the space required for the storage of materials at the machine and for loading and unloading it; auxiliary tools, benches, jigs, and the like; and the free and safe movement of the workman while working which, for administrative and accounting purposes, is considered a unit.

Production Control--The procedure of planning, routing, scheduling, dispatching, and expediting the flow of materials, parts, subassemblies, and assemblies within the plant from the raw state to the finished product in an orderly and efficient manner.

Production Cost Center--Units, functions, or areas where a particular type of work is done (sometimes called direct cost centers).

Production Engineering--The function of planning where and when to perform work necessary to produce a product and of coordinating internal and external orders, delivery dates, workman, machines, and the like, thereby promoting efficient operation.

Production Load--The demand for output established by scheduling based on consumer orders or sales forecasts. Usually it is stated in terms of the time required to produce the demanded output or as a percent of capacity output, normal output, available machine-hours, or the like.

Production Lot--Quantity of parts that a contractor makes at one time.

Production Planning--The systematic scheduling of men, materials, and machines by using lead times, time standards, delivery dates, work loads, and similar data for the purpose of producing products efficiently and economically and meeting desired delivery dates.

Production Standard--See Performance Standard.

Productivity--The actual rate of output or production per unit of time worked.

Profit--Excess of income realized over costs incurred (also fee).

Prorated Costs--Costs that are divided or distributed proportionally to different products, cost centers, or contracts.

Prototype Costs--The costs incurred during the manufacture of the original (or model) in the pre-production phase of the procurement cycle.

Prototype Factor--A factor to increase the standard time due to start up conditions and non-standard manufacturing methods employed on initial units before learning occurs.

Provisioning--Activity associated with spares, initial outfitting and associated documentation.

Purchase Lot--Quantity of raw materials or parts that a contractor buys at one time.

Quality Assurance--An engineering discipline which designs procedures for testing and measuring the functionality of the finished product.

Quality Control--The procedure of measuring the variation in size, weight, finish, etc., for products or services and of maintaining the resulting goods or services within these limits.

Rate--To estimate the worth or value of anything by comparing it with a standard or scale as, for instance, in performance rating.

Rate Setting--The establishing of production standards by time study, predetermined motion times, standard data, time formulas, or some other means.

Ratio Delay Study--See Work-Sampling Study.

Ratio of Support--A method of estimating support costs based on prior contract cost data which shows a percentage relationship between support hours and direct factory labor hours.

Realization Factor--The ratio of actual performance time to standard performance time, usually expressed as a decimal number.

Recurring Effort--An effort repeated during a contract's duration.

Reoperation--Any work done on material or an item in order to correct work done improperly or to comply with revisions in design or specifications.

Repetitive--The general term used when referring to processes, operations, elements of operations, or the products resulting therefrom that occur or are produced over and over again with negligible variation. The term must be qualified or explained when it is used in order to have a concrete meaning.

Replaceable Assembly--An assembly that is capable of being easily removed and replaced as an integral item.

Residual Inventory--An inventory or stores location of spare or unused parts purchased on previous contracts. It should be screened as to usable parts for each subsequent contract and priced at the lower of market or cost.

Rework--See Reoperation.

RFP--Request for Proposal--Package of information submitted to prospective bidders which specifies the products required and the form and content of cost and price data backup.

Sampling--The practice of selecting a small portion (usually determined statistically) of the total group under consideration for the purpose of inferring the value of one or several characteristics of the group.

Scheduling--The prescribing of when and where each operation necessary to the manufacture of a product is to be performed.

Scrap--Residual material resulting from machine or assembly processes, such as machine shavings, unusable lengths of wire, faulty parts.

Select Time--See Leveled Time.

Semivariable Costs--Costs which vary according to the number of units produced but not proportionately.

Service Cost Center--Generally indirect costs are accumulated for such as building, machinery, equipment and power plant maintenance (Indirect Cost Center).

Setup--Making ready or preparing for the performance of a job or operation. Machine setup involves equipping a machine with the appropriate accessories, tools, and fixtures, setting the proper feed, speed, and depth of cut, and so forth. In manual work, setup is the arrangement prior to commencing the work, of the tools, accessories, component parts, and details involved. It also includes the teardown to return the machine or work area to its original or normal condition.

Should-Cost Estimate--A highly detailed, long-term cost analysis developed for the Government's use in determining what a defense system *should* cost.

Shrinkage--An additional quantity of material added to the quantity listed on the Bill of Material to provide for spoilage, scrap, waste and natural attrition (see Attrition).

Slope (of an experience curve)--A percentage figure that represents the steepness (rate of improvement) of the curve; colloquially, the end line.

Software--Documentation in the form of drawings, manuals, processed data, etc., serving as support for contract hardware or even as contract deliverable items.

Sole Source--Non-competitive award of contract to a qualified contractor.

Special Factor--A factor or circumstance which influences a contractor either to "make" a part at his own facilities or to "buy" the finished part from a private vendor.

Special Time Allowance--A temporary time value applying to an operation in addition to or in place of a standard allowance in order to compensate for a specified, temporary, non-standard production condition.

Spoilage--A form of waste material resulting from misuse of material or errors in workmanship.

Standard--See Performance Standard, Standard Time, Standard Hour, Direct-labor Standard, Guaranteed Standard, and so on.

Standard Cost--The normal expected cost of an operation, process, or product including labor, material, and overhead charges, computed on the basis of past performance costs, estimates, or work measurement.

Standard Data--See Standard Time Data.

Standard Hour--An hour of time during which a specified amount of work of acceptable quality is or can be performed by a qualified workman following the prescribed method, working at normal pace, and experiencing normal fatigue and delays.

Standard Part--A part for which a military specification has been written documenting the part's physical nature, price, and source.

Standard Time--The time which is determined to be necessary for a qualified workman, working at a pace which is ordinarily used under capable supervision and experiencing normal fatigue and delays, to do a defined amount of work of specified quality when following the prescribed method.

Standard-time Data--A compilation of all the elements that are used for performing a given class of work with normal elemental time values for each element. The data are used as a basis for determining time standards on work similar to that from which the data were determined without making actual time studies.

Subassembly--Two or more parts joined together to form a unit which is only a part of a complete machine, structure, or other article.

Subcontracted Item--A part, component, assembly, or service produced or performed by other than the prime contractor but in accordance with his design and direction. This may be accomplished through a subcontract or purchase order.

Support Costs--Direct and indirect costs not directly attributable to the actual, physical fabrication and assembly of an end item.

Time Standard--See Standard Time.

Time Study--The procedure by which the actual elapsed time for performing an operation or subdivisions or elements thereof is determined by the use of a suitable timing device and recorded. The procedure usually but not always includes the adjustment of the actual time as the result of performance rating to derive the time which should be required to perform the task by a workman working at a standard pace and following a standard method under standard conditions.

TMU--Time-measurement unit--equals 0.00001735 hour (approximately one-sixteenth of a second) but generally used as 0.00001 hour (about one-twenty-eighth of a second).

Tolerance--A measure of the accuracy of the dimensions of a part or the electrical characteristics of an assembly or function.

Total Package Procurement--A contract concept which provides simultaneously for the purchase of all required operating hardware plus all software, including training and services and provisioned spares.

Unavoidable Delay--A production delay that the operator cannot prevent.

Unavoidable-delay Allowance--Time included in the production standard to allow for time lost which is essentially outside the workman's control; as, interruption by supervision for instruction, waits for crane, or minor adjustments to machines or tools (usually applied as a percentage of the leveled, normal, or adjusted time).

Unit Costs--Cost per single unit generally direct costs only, but sometimes with indirect costs prorated.

Unit Curve--A line drawn on a graph representing the man-hours (or cost) of each unit.

Unitized Construction--A type of unit construction consisting predominately of replaceable assemblies.

Unit One--The first complete system or end product (or its associated cost) to be produced on a production contract. Usually associated with the first unit on the X-axis of an experience curve.

Variable Expense--Expenditures that vary in proportion to the volume of production, such that an increase/decrease in production causes an increase/decrease in the variable cost.

Variance--The difference between any standard or expected value and an actual value. For example, the difference between the established standard cost and the cost actually incurred in performing a job or operation.

Wage-incentive Plan--A method of payment which directly relates earnings to production. A system which enables workmen to increase their earnings by maintaining or exceeding an established standard of performance.

Waiting Time--See Downtime.

Waste--Scrap and Spoilage which result from errors of manufacture and excess material (shavings, etc.).

Work Aid--A device such as a pattern, template, or sketch used to enhance a worker's ability to learn and perform a task efficiently.

Work Breakdown Structure--A means of structuring the product and its associated costs so as to provide an orderly way of accumulating contract costs at any desired assembly or work package level.

Work Cycle--A pattern of motions and/or processes that is repeated with negligible variation each time an operation is performed.

Work Package--Identification of a specific set of tasks required to accomplish an activity (see Work Breakdown Structure (WBS)).

Work Sampling Study--A statistical sampling technique employed to determine the proportion of delays or other classifications of activity present in the total work cycle.

Appendix A. EXPERIENCE CURVES

INTRODUCTION

The earliest known work in the time/cost relationship known today as the experience curve was published in 1936 by T.P. Wright. His article, "Factors Affecting the Cost of Airplanes," has evoked the controversy expected by Mr. Wright, who said that "this subject is one which can always be relied upon to start a discussion whenever it is raised in aircraft circles. Great differences of opinion will be voiced as to the relative importance of various factors, depending somewhat on whether the discussion is between persons in the industry who are engaged in sales, engineering, design or factory work." Mr. Wright was indeed prophetic; controversy still exists some 36 years later.

Mr. Wright's hypothesis, that the cumulative average labor cost for any quantity of airplanes produced decreases by a constant amount as the quantity of airplanes is doubled, was initially called and still is commonly called the learning curve. The learning curve, both in concept and in use, has been subjected both to praise and to criticism. Because it is mathematically complex to those of us who are not mathematicians, industrial engineers, and the like, and because its derivation, application, and accuracy as an estimating tool are controversial, the following explanations are presented to give a concise, simplified, and objective treatment of this subject.

TERMINOLOGY

Before exploring the technical aspects of this subject, some terms must be defined clearly. The terms "learning curve," "improvement curve," "experience curve," " cost-reduction curve," " manufacturing-time forecasting curve," "Wright curve," "Crawford curve," and "Stanford-B curve," all are nearly synonymous. Each of these terms is an expression of the notion that costs decrease as learning or experience increases.

Costs may be expressed in actual dollars or in the basic elements of cost--namely, direct labor hours and units of material. Many persons logically assume that the term "learning curve" applies to direct labor hours; but depending on individual company vernacular, it could apply to the entire procurement cost. Conversely, "cost curve" implies a conglomerate of costs, but that term may well mean direct labor learning expressed in dollars instead of man-hours. Because of the differences in company vernaculars, a prerequisite to any examination is to identify the ingredients that make up the curve under study.

Historically, "learning curve" has referred to worker learning. Although worker learning does contribute to a reduction in man-hours or cost during a production process, it is not always clear just how much of the total reduction can be attributed to worker learning. Worker learning, per se, is confined to memorization and motor response improvement. In an assembly operation, for example, the sequence of tasks for putting into place a bolt, washer, lock washer, nut as opposed to bolt, lock washer, nut, are memorized, and the movements of reaching and grasping and the position applicable to each movement are "learned" while general dexterity improves. Memory of methods and improvement of dexterity do occur over time, and that they are factors contributing towards cost reduction is indisputable. But management initiates factors that may be equal to or greater than the individual worker's contribution toward total cost reduction. Some of these factors are:

- The development of more efficient tools, machines, and processes
- The solution of engineering problems
- The use of subcontractors
- The simplification of designs
- The increase of efficiency in the procurement and handling of material
- Simplified procedures, value engineering, sophisticated tooling, automation

The relative impact of these factors on each other as well as to overall cost reduction will vary from company to company, department to department, and product to product, and so worker learning cannot be considered necessarily the single most significant contributor to time/cost reduction. The term "learning curve," therefore, may be inadequate.

The term "experience curve" may be more appropriate than "learning curve" because experience (that is, history documented in empirical data) furnishes the data points from which these variously named curves are plotted. "Experience" (or "history") can apply to any of several areas, (such as, labor, material, or gross cost, whereas the term "learning" might be cumbersome when addressing topics other than direct labor. Therefore, in this discussion, the term "experience curve" will be used to cover the general case.

DEFINITIONS

As a prerequisite to understanding Mr. Wright's hypothesis, certain key phrases listed below must be learned.

- *Slope of the Curve*--A percentage figure that represents the steepness (constant rate of improvement) of the curve. Using Wright's hypothesis, this percentage represents the value (e.g., man-hours or cost) through each doubled production quantity in relation to the previous quantity. For example, with an experience curve having an 80 percent slope, the value at unit two is 80 percent of the value of unit one, the value at unit four is 80 percent of the value at unit two, the value at unit 1,000 is 80 percent of the value at unit 500, and so on.

- *Unit one*--The first unit of product actually completed during a production run. This is not to be confused with a unit produced in any preproduction phase of the overall procurement program.

- *Cumulative Average Man-Hours**-- The average man-hours expended per unit for all units produced through any given unit. When illustrated on a graph by a line drawn through each successive unit, the values form a *cumulative average curve*.

- *Unit Man-Hours*--The total direct labor hours expended to complete any specific unit. When a line is drawn on a graph through the values for each successive unit, the values form a *unit curve*.

- *Cumulative Total Man-Hours*--The total man-hours expended for all units produced through any given unit. The data plotted on a graph with each point connected by a line form a *cumulative total curve*.

The data in table A-1 illustrate Wright's cumulative average phenomenon and the derived unit and cumulative total data.

Figure A-1 graphically shows the cumulative average "curve"; figure A-2 shows the relationship between the cumulative average and unit "curves." As you can see, the shape of a curve appears when the line is drawn on conventional graph paper.

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*For simplicity and consistency, the experience curves in this discussion hereafter will be considered as applicable to direct manufacturing labor, and cost values will be expressed as "man-hours" or "labor hours."

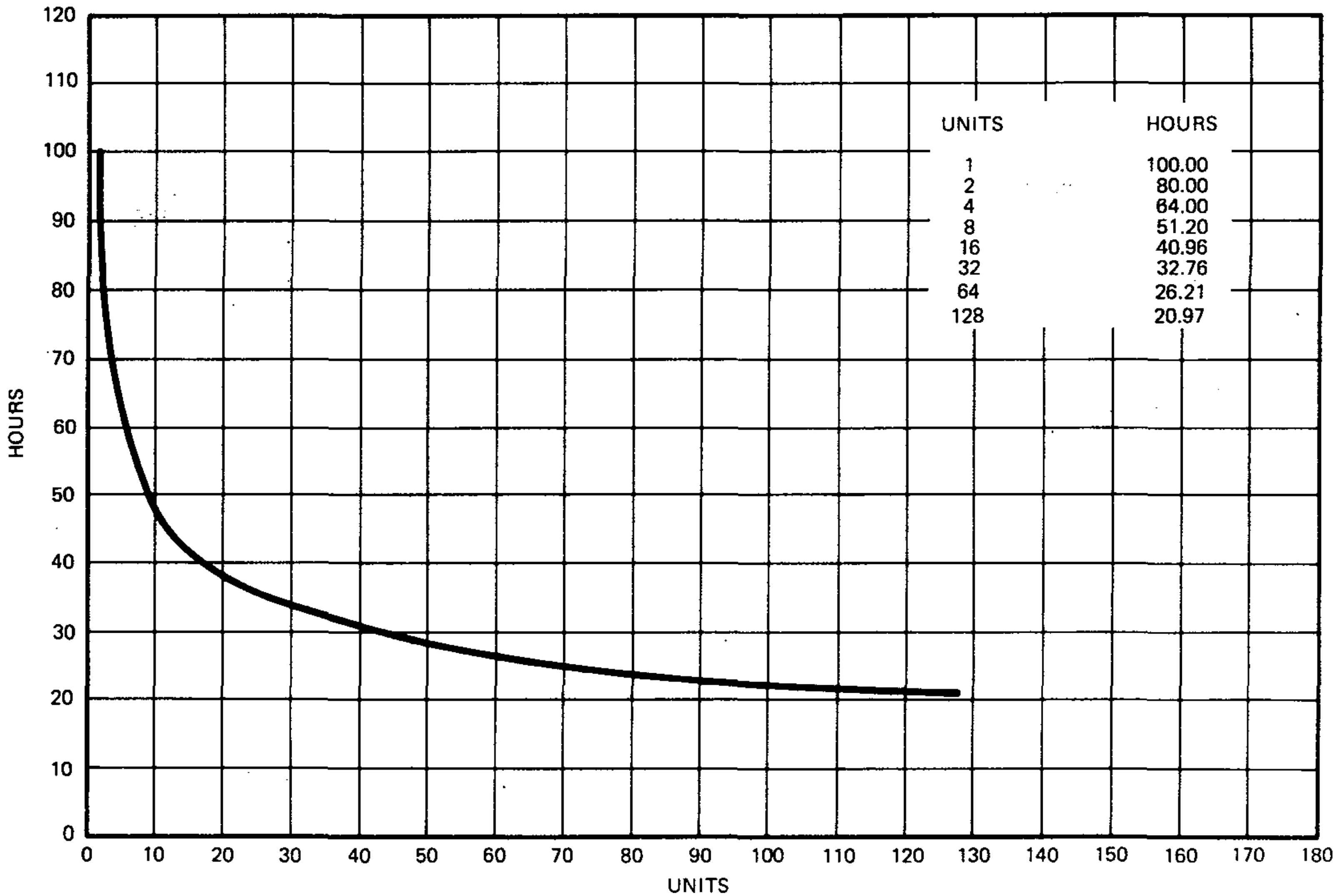

Figure A-1. Eighty Percent Cumulative Average Curve--Wright Method

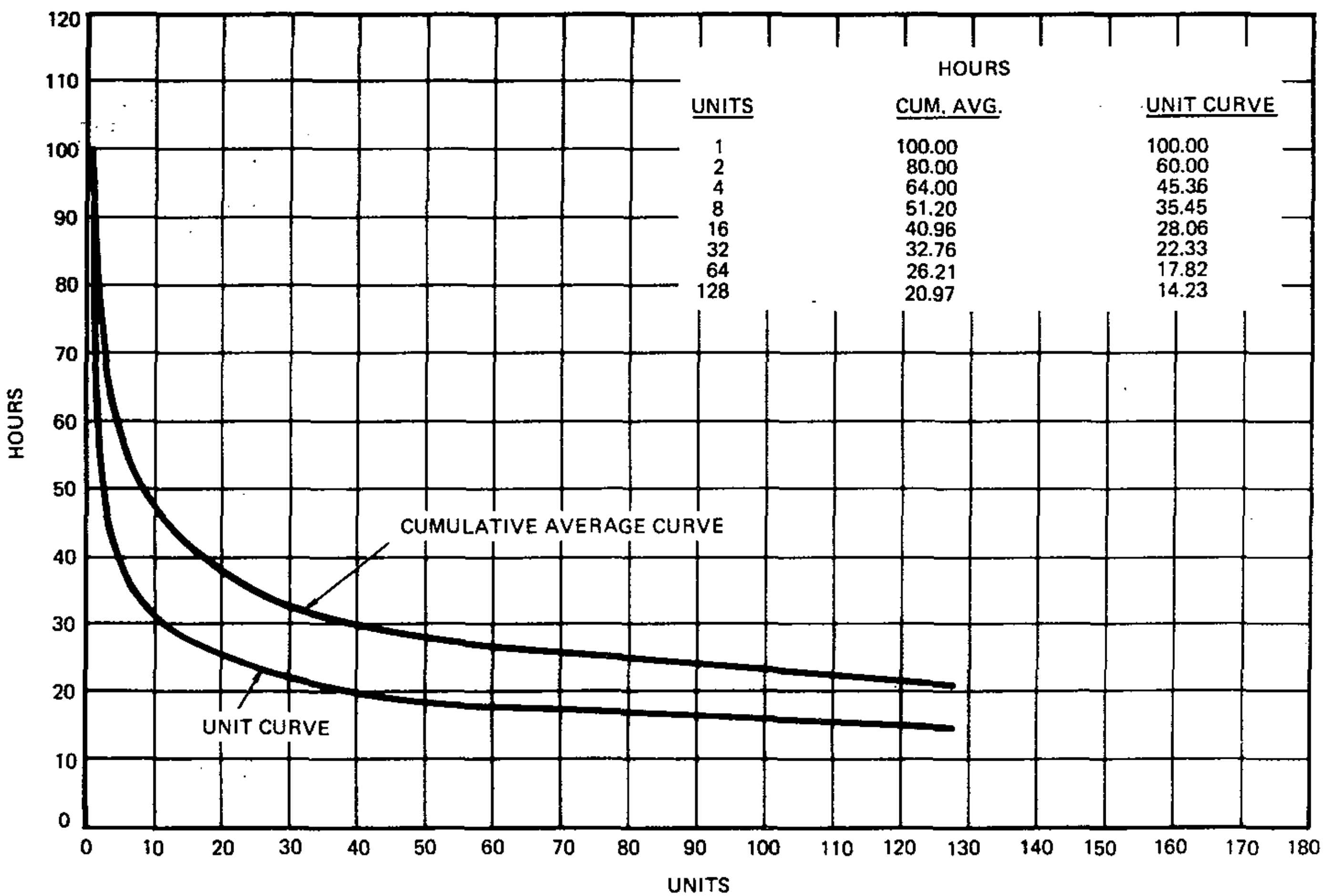

Figure A-2. Eighty Percent Cumulative Average Curve with Corresponding Unit Curve--Wright Method

Table A-1. Wright's Hypothesis with an 80 Percent Slope

Units	Cumulative Average Curve	Unit Curve	Cumulative Total Curve
1	100.00	100.00	100.00
2	80.00	60.00	160.00
4	64.00	45.36	256.00
8	51.20	35.45	409.60
16	40.96	28.06	655.36
32	32.76	22.33	1048.57
64	26.21	17.82	1677.72
128	20.97	14.23	2684.35
256	16.77	11.38	4294.96

BASIC MATHEMATICS OF THE CUMULATIVE AVERAGE CURVE

Fortunately, the type of data in table A-1 for various slopes and units has been published for general use in tabular form (the use of these tables is described later in this appendix). Nevertheless, in order to explain the bases for experience curves, to prepare you for the recognition of the available formulas, and to introduce the use of log-log paper for the construction of curves, the derivation of curve data will be explained here.

The cumulative average data in table A-1 may be obtained from the following formula:

$$T_a = T_1 X^{-K}$$

when:

T_a = cumulative average direct labor hours

T_1 = the direct labor hours for the first unit, (unit one)

X = the cumulative unit produced

$-K$ = the slope of the experience curve (for example, under the Wright Method or the "one-third law," the exponent for an 80 percent curve is -0.321928)

The best solution for this formula is through the use of logarithm tables and is expressed as:

$$\text{Log } T_a = -K \text{ Log } X + \text{Log } T_1$$ (see table A-2 for -K values)

Because the complete rationale for this formula is beyond the scope of this guide, we recommend you read *Project Estimating by Engineering Methods*, chapter 9, which gives excellent coverage of this subject. Also, because algebraic formulas, exponents (-K), and logarithms are involved, the use of graph paper with a logarithmic scale rather than an arithmetic scale would be expedient and preferable.

Table A-2. Experience Curve Exponents (-K)*

Slope	Exponent	Slope	Exponent	Slope	Exponent
50	1.000000	67	.577767	84	.251539
51	.971431	68	.556393	85	.234465
52	.943416	69	.535332	86	.217591
53	.915936	70	.514573	87	.200913
54	.888969	71	.494109	88	.184424
55	.862496	72	.473931	89	.168123
56	.836501	73	.454032	90	.152003
57	.810966	74	.434403	91	.136061
58	.785875	75	.415037	92	.120294
59	.761213	76	.395929	93	.104697
60	.736966	77	.377070	94	.089267
61	.713119	78	.358454	95	.074001
62	.689660	79	.340075	96	.058894
63	.666576	80	.321928	97	.043943
64	.643856	81	.304006	98	.029146
65	.621488	82	.286304	99	.014500
66	.599462	83	.268817		

*The figures in this table represent the negative experience curve exponent (-K) in the equation $T_a = T_1 X^{-K}$

Note: See page 107 of *Alpha & Omega and the Experience Curve* for a complete table including fractional parts of the slopes.

LOG-LOG PAPER*

The cumulative average curve is illustrated on ordinary square graph paper (arithmetic scale) in figure A-1. The slope of the curve is clearly visible, and the decrease in hours as the quantity increases is readily discernible. When experience curves are drawn on graph paper with "multiple" logarithmic scales (that is, on log-log paper), the visual appearance of a "curve" is lost. Most experience "curves" are drawn on log-log paper.

Several advantages that overshadow the singular disadvantage of losing the visual effect of the curve are:

- Because of its mathematical relationships, the cumulative average curve is linear (a straight line) when drawn on log-log paper.

- The curve can be drawn from a minimum of data. If any two points or one point and the slope are known, the curve can be drawn. *But, as the number of points plotted increases, the accuracy of the curve increases.*

- The curve may be extended to any desired unit within the bounds of the logarithmic scales, with the use of a straight edge.

- A straight line usually can be extended more accurately than can a nonlinear (curved) line.

- If actual data are plotted on log-log paper, an approximate slope can readily be obtained by using a triangle and a straight edge, and production programs can be roughly planned without reference to experience curve tables.

To accomplish the above on ordinary square graph paper, multiple points along the scale must be calculated and plotted, and then connected with a nonlinear (curved) line.

Figures A-3 and A-4 illustrate the data from table A-1 plotted on log-log paper. When comparing figure A-1 with figure A-3 and figure A-2 with figure A-4, the visual effects are different but the mathematical effects are identical.

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*There are several varieties of log-log paper, with each variety reflecting a particular number of cycles (power of ten) scaled on the sheet. The log-log paper used for figure A-3, for example, is 2-cycle by 3-cycle paper. On the left side of the figure (y axis) are two basic divisions, 1 through 10 and 10 through 100; because 10^2 equals 100, this side of the paper is 2-cycle. Similarly, the x axis has three basic divisions, 1 through 10, 10 through 100, and 100 through 1,000; because 10^3 equals 1,000, this side of the paper is 3-cycle.

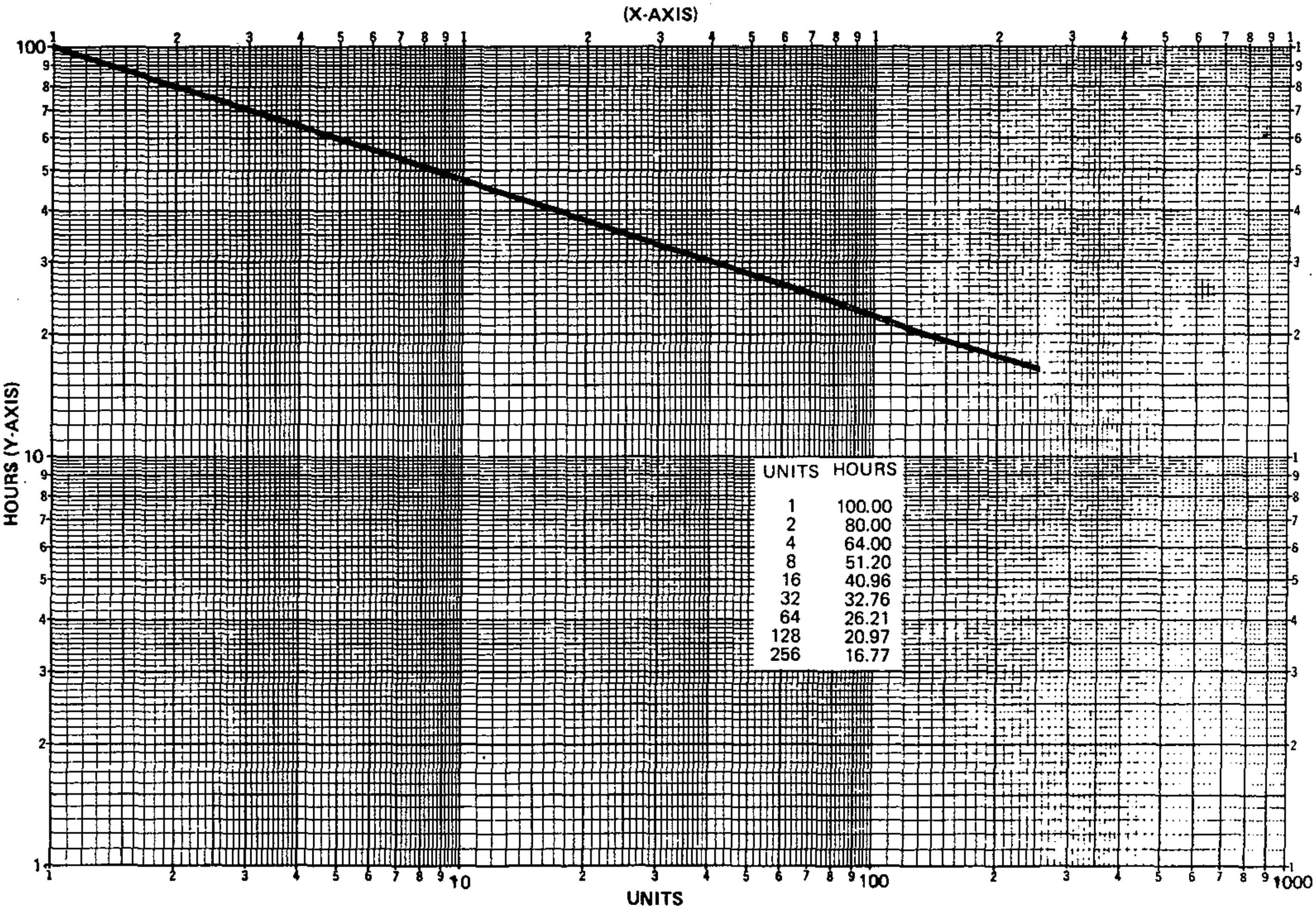
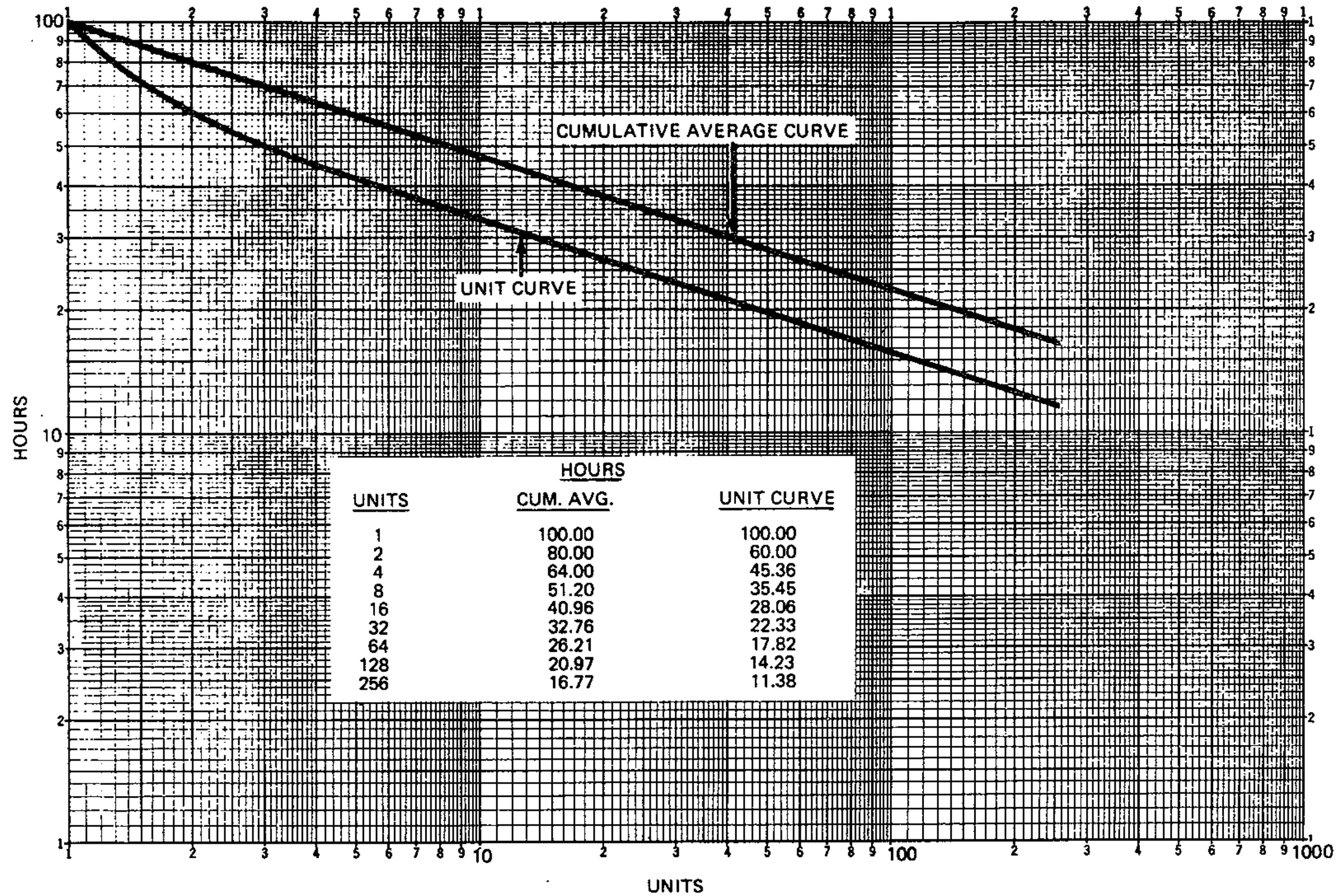


Figure A-3. Eighty Percent Cumulative Average Curve on 2- by 3-Cycle Log-Log Paper--Wright Method



UNITS	HOURS CUM. AVG.	HOURS UNIT CURVE
1	100.00	100.00
2	80.00	60.00
4	64.00	45.36
8	51.20	35.45
16	40.96	28.06
32	32.76	22.33
64	26.21	17.82
128	20.97	14.23
256	16.77	11.38

Figure A-4. Eighty Percent Cumulative Average Curve with Corresponding Unit Curve--Wright Method

Note that if the curves plotted in figures A-2 and A-4 were extended far enough, they would *approach* zero. In both cases, the data when extended indefinitely become "asymptotic": they will approach but never reach zero.

The following technique (quick method) may be used to verify any particular slope:

(1) Choose some value on the unit axis (x axis), and from the point of intercept with the curve, find the corresponding man-hour value on the y axis. Let this man-hour value be Y_1.

(2) Find the value on the curve that corresponds to 2X and let this corresponding value be Y_2.

(3) Slope = $\frac{Y_2}{Y_1}$

Example:

(A) $X = 20$ $\qquad$ $2X = 40$

$Y_1 = 381$ $\qquad$ $Y_2 = 305$

$$\frac{Y_2}{Y_1} = \frac{305}{381} = 80.05\%$$

This example is shown graphically in figure A-5.

The cumulative total data of table A-1 have not been displayed yet because of the difficulty in plotting the values within the limits of figures A-1 through A-4. They are shown in figure A-6, insofar as possible, through rescaling the log-log paper. But even in this figure the bounds of the paper limit the plotting of these values to those through unit 16. In order to display fully the cumulative total curve, the logarithmic scale would have to be adjusted further or 3-cycle by 3-cycle log-log paper used. These options would not be available on ordinary 8-1/2-inch by 11-inch square graph paper without losing the visability associated with the other two curves.

A quick method to determine a cumulative total value from cumulative average data is to multiply the cumulative average value by the number of units desired. For example, to obtain the cumulative total through unit four, multiply the cumulative average of 64.00 by four. The answer is 256.00. Conversely, to obtain the cumulative average value from a cumulative total, again using the data in table A-1, divide the cumulative

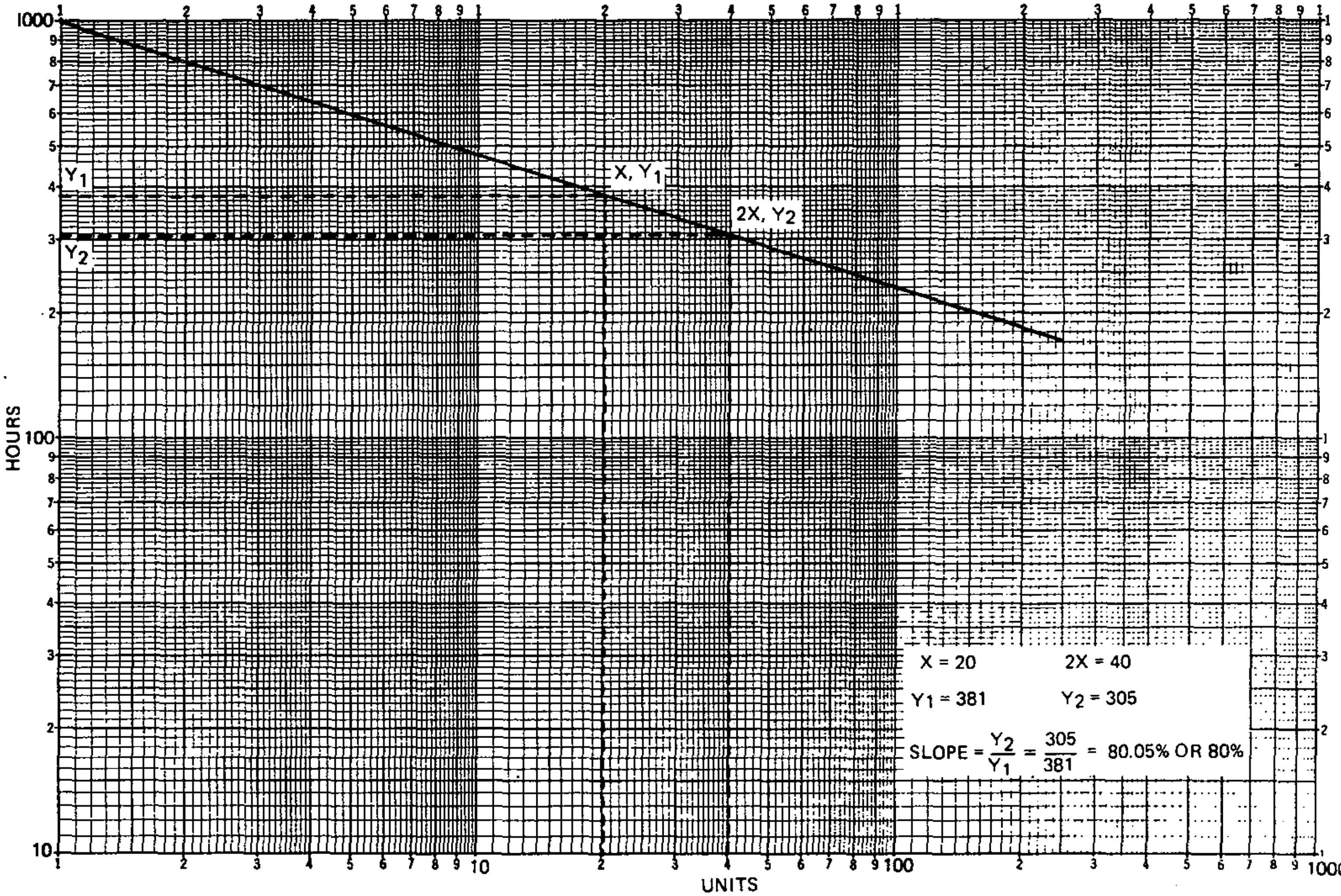
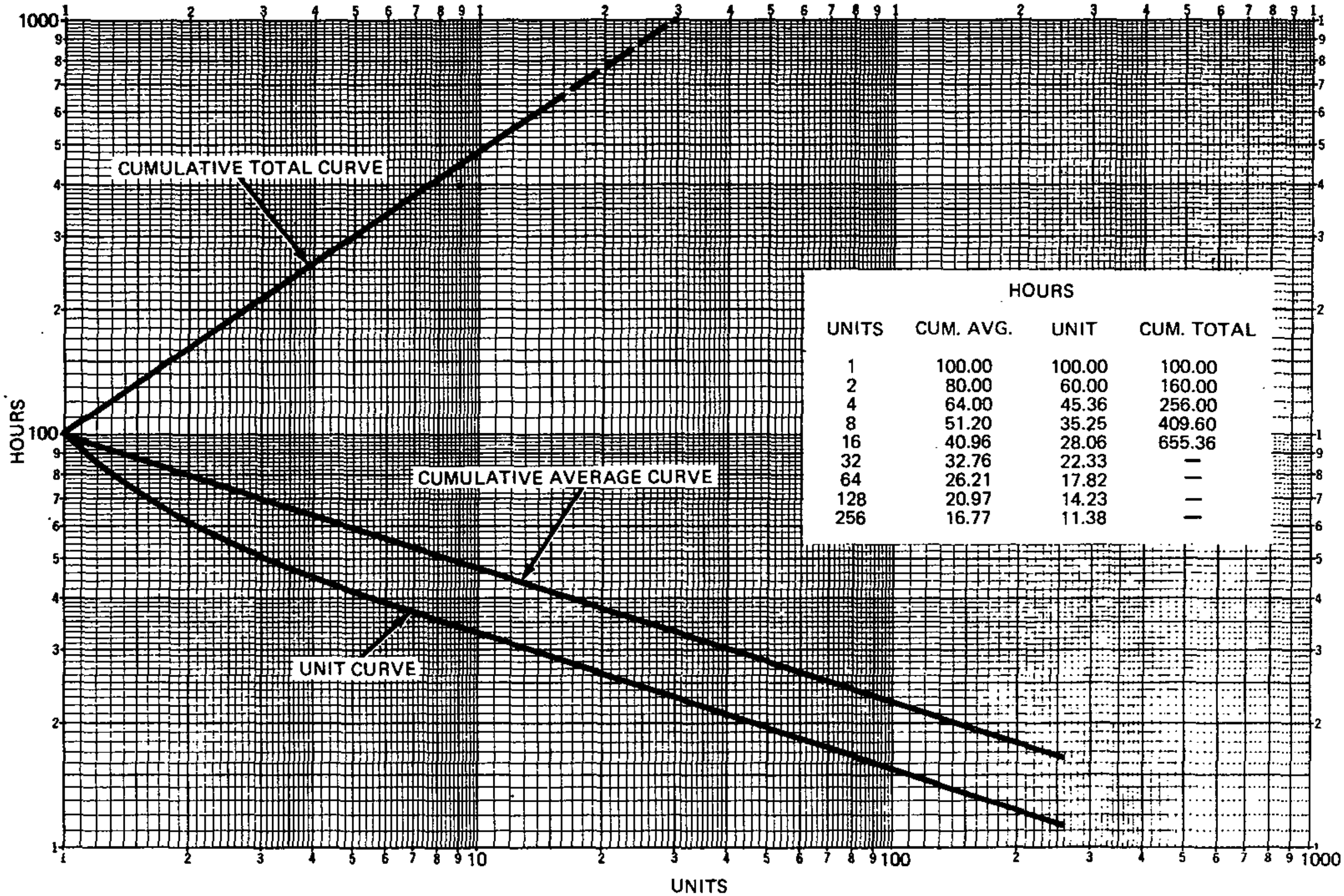


Figure A-5. Quick Method for Calculating the Slope of a Cumulative Average Curve



	HOURS		
UNITS	CUM. AVG.	UNIT	CUM. TOTAL
1	100.00	100.00	100.00
2	80.00	60.00	160.00
4	64.00	45.36	256.00
8	51.20	35.25	409.60
16	40.96	28.06	655.36
32	32.76	22.33	—
64	26.21	17.82	—
128	20.97	14.23	—
256	16.77	11.38	—

Figure A-6. Eighty Percent Cumulative Average Curve with Corresponding Unit and Total Cumulative Curves total of 409.60 by eight and the cumulative average through unit eight (51.20) is obtained. This method is much simpler for general use than the following algebraic formula:

$$\text{Cumulative total} = T_C = T_1X^{(1-K)}$$

The unit curves in figures A-4 and A-6 are visible curves, despite being on log-log paper, which is in contrast to the straight lines for the other curves. The relationship between the unit and cumulative average curves is discussed later.

MANUAL CONSTRUCTION OF A CUMULATIVE AVERAGE CURVE

There are several methods by which a cumulative average curve can be constructed when only the slope and the base point (that is, the number of man-hours expended to complete a given number of cumulative units) are available. These methods are described below.

ANGLE OF THE CURVE

The correct angle from the horizontal can be drawn from the top left cycle through the base point. In the case of an 80 percent cumulative average curve, this angle is 17 degrees, 50 minutes. A guide to appropriate angles for other curves is provided in table A-3.

Table A-3. Angles for 75 Through 96 Percent Curves*

Slope(%)	96	95	94	93	92	91	90	89	88	87	86
Degrees	3	4	5	5	6	7	8	9	10	11	12
Minutes	23	13	7	58	51	44	38	32	26	21	16
Slope(%)	**85**	**84**	**83**	**82**	**81**	**80**	**79**	**78**	**77**	**76**	**75**
Degrees	13	14	15	15	16	17	18	19	20	21	22
Minutes	11	8	2	58	54	50	46	44	39	36	33

*See figure A-7 for examples. Note: The use of angles is restricted to log-log paper with the understanding that mathematical accuracy is limited.

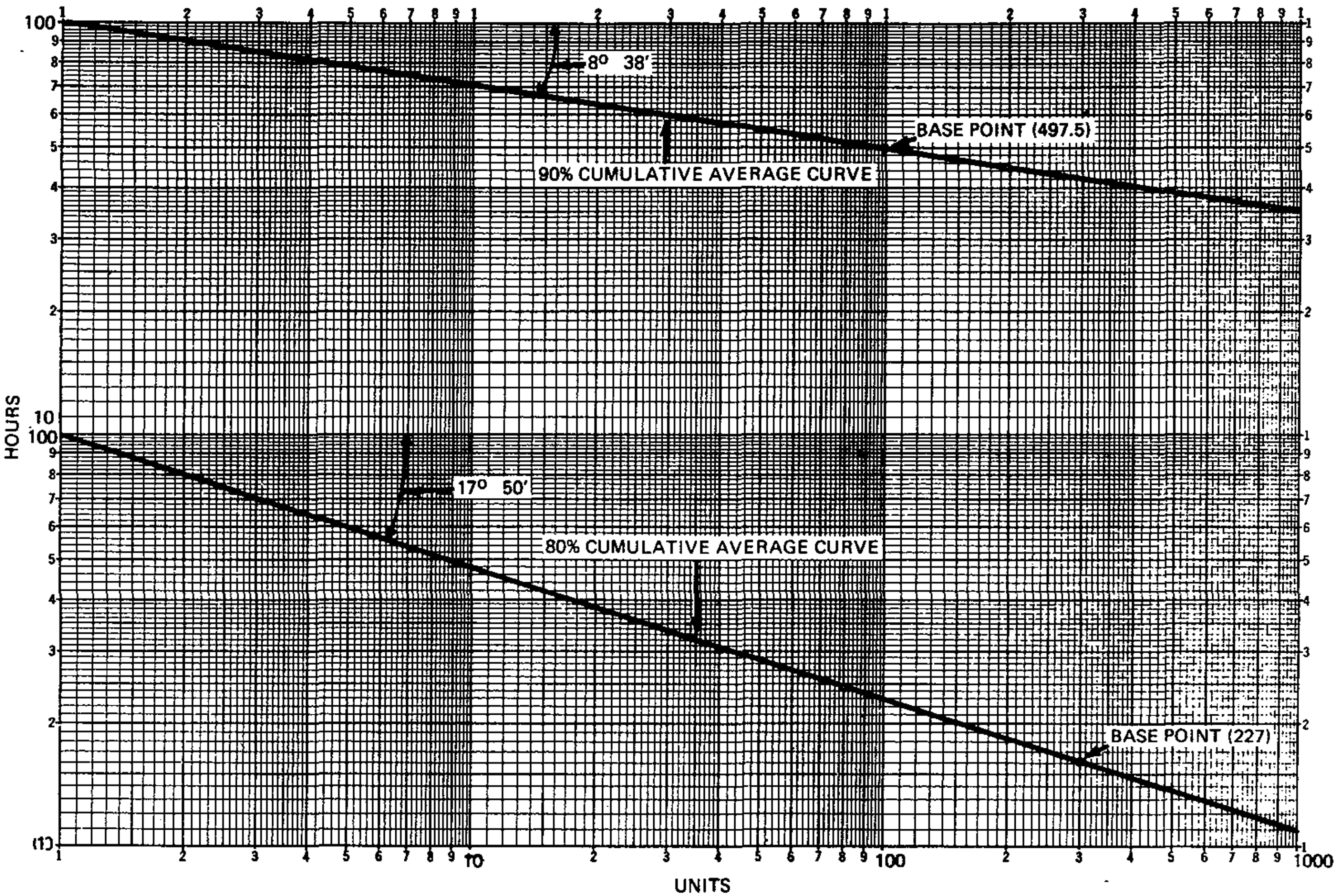


Figure A-7. Angles for a 90 Percent (Upper) and an 80 Percent (Lower) Cumulative Average Curve

TRIANGULAR METHOD

Figures A-8 and A-9 contain two methods for constructing a cumulative average curve with a triangle and straight edge.

UNIT CURVES (WRIGHT METHOD)

Because Wright's original hypothesis pertained to the cumulative average curve, the unit curve is derived from cumulative average data. The unit curve may be obtained from either of the two following methods:

- The algebraic formula method:

$$T_u = T_1 X^{(1-K)} - [T_1 \ (X-1)^{\ (1-K)}]$$

when:

T_u = unit value desired

T_1 = unit one

X = quantity

-K = slope

- The "quick technique" using the relationship between the cumulative average and unit curves:

The curves in figure A-4 are *almost* parallel after the fifth unit. Also, prior to unit five, the unit curve actually "curves" on log-log paper, whereas the cumulative average curve is a straight line. Listed in table A-4 are the relationships (for specific quantities) between curves for other cumulative average slopes. These relationships can be used to convert cumulative average curves into corresponding unit curves.

In other words, when the cumulative average curve has an 80 percent slope, by multiplying the cumulative average value through unit 1,000 by 0.678 the unit curve value for unit 1,000 can be obtained. At unit 100 this relationship is 0.679, at unit ten it is 0.689, at unit four it is 0.709, and at unit two it is 0.750. Although these relationships are not absolutely accurate when used for obtaining values other than for those specific quantities, they are accurate enough for general use.

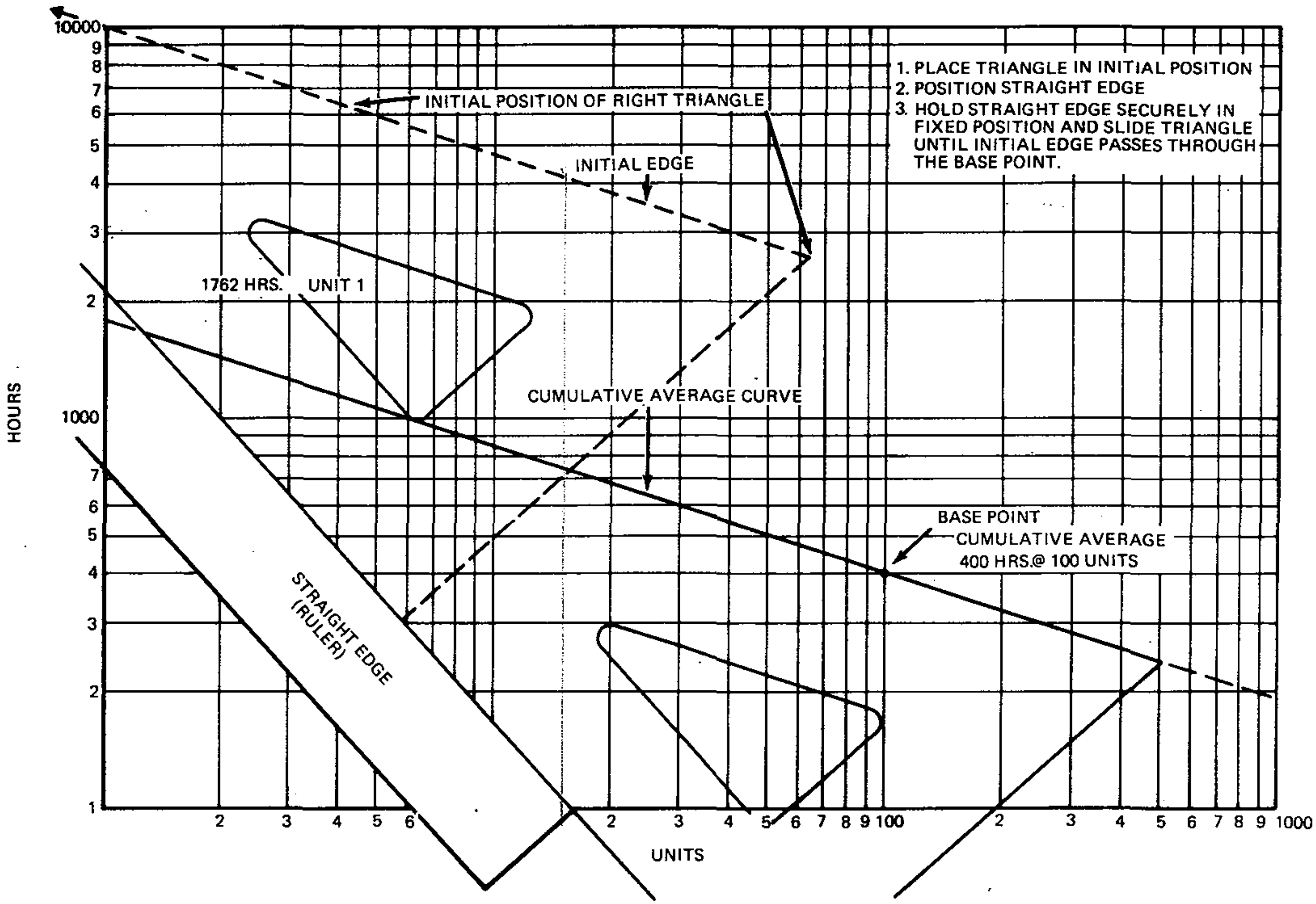


Figure A-8. Transposing a Given Slope Through a New Base Point

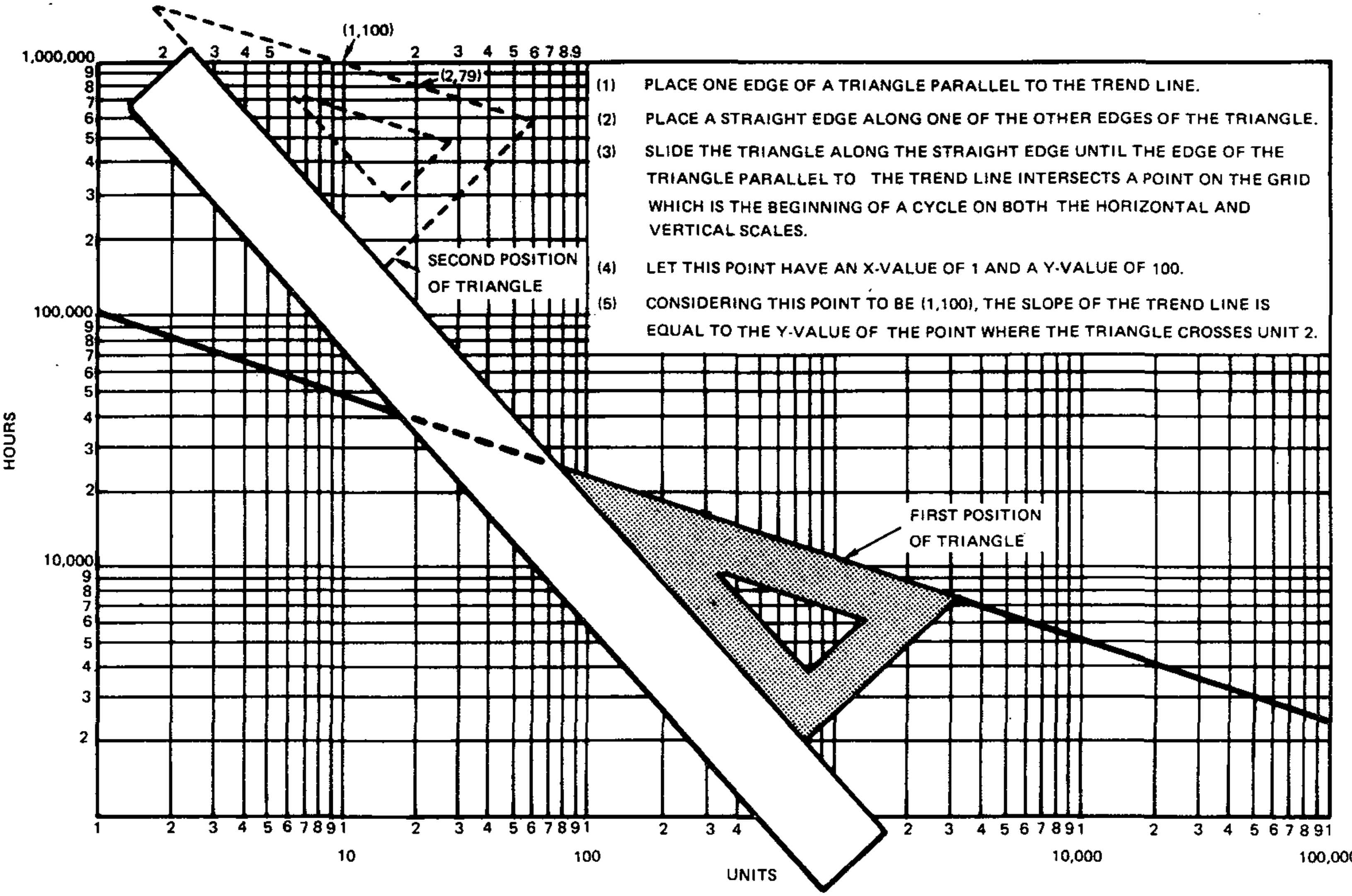


Figure A-9. Charting the Slope

Because the unit curve does not result from the same algebraic formula that the cumulative average curve results from, it does not have the same properties as the cumulative average curve (it is not a straight line on log-log paper). During the initial few units the unit curve is much steeper than the cumulative average curve. Referring to table A-1, unit two on the cumulative average curve has a value that is 20 percent (constant) less than unit one; on the unit curve the value for unit two is 60 percent less than unit one, and the value for unit four is approximately 25 percent less than that for unit two. Because there is no constant for these quantities, the line is curved rather than straight.

Table A-4. Relationships Between Cumulative Average Curve and Unit Curve

	Slope (%)										
Unit	96	95	94	93	92	91	90	89	88	87	86
2	0.958	0.947	0.936	0.925	0.913	0.901	0.889	0.876	0.864	0.851	0.837
4	0.949	0.935	0.922	0.908	0.894	0.880	0.866	0.851	0.837	0.821	0.805
10	0.947	0.930	0.905	0.900	0.885	0.870	0.855	0.839	0.823	0.807	0.791
100	0.941	0.926	0.911	0.895	0.880	0.865	0.849	0.833	0.816	0.800	0.783
1000	0.941	0.926	0.911	0.895	0.880	0.864	0.848	0.832	0.816	0.799	0.782
	Slope (%)										
Unit	85	84	83	82	81	80	79	78	77	76	75
2	0.824	0.810	0.795	0.780	0.765	0.750	0.734	0.718	0.701	0.684	0.667
4	0.791	0.775	0.759	0.746	0.726	0.709	0.692	0.674	0.656	0.638	0.620
10	0.775	0.758	0.741	0.724	0.707	0.689	0.672	0.654	0.635	0.617	0.598
100	0.766	0.749	0.736	0.715	0.697	0.679	0.661	0.643	0.624	0.605	0.586
1000	0.766	0.748	0.731	0.714	0.696	0.678	0.660	0.642	0.623	0.604	0.585

CHANGING FROM A CUMULATIVE AVERAGE CURVE TO A UNIT CURVE

With these relationships established, it is possible to construct a unit curve from a cumulative average curve without too much difficulty, the cumulative average curve having been constructed by one of the several methods previously mentioned. Shown in figure A-10 is how these relationships are used when plotting the unit curve from an existing cumulative average curve without computing each unit value. Given that the cumulative average time through 500 units is 800 man-hours and the slope is 80 percent, the base point can be established and the curve constructed by either of the two previously described methods. Using table A-4 the relationship between the base point and a corresponding point on the unit curve is 0.678. Therefore, the corresponding value on the unit curve is 542.0 man-hours (800 x 0.678). This process was repeated for unit 70 (1500.0 x 0.679 = 1018.5) and unit 2 (4800 x 0.750 = 3600.0), and a unit curve was constructed.

CHANGING FROM A UNIT CURVE TO A CUMULATIVE AVERAGE CURVE

Figure A-11 illustrates that a cumulative average curve may be plotted from unit curve data without a series of individual cumulative average points having been computed. Given a base point of 80.0 man-hours expended to produce unit number (specifically) 256 on the unit curve for an 80 percent cumulative average curve, the corresponding value on the cumulative average curve may be determined. Using table A-4, the relationship can be found to be 0.678; therefore, the cumulative average value for unit 256 is 118.0 (80/0.678). The cumulative average curve then may be constructed by either of the aforementioned methods or corresponding values plotted from unit curve data through the use of table A-4 (for example, unit 100 = 108.6/0.679 = 160.0; unit 50 = 137.8/0.689 = 200.0; unit two = 435.0/0.750 = 580.0).

CRAWFORD METHOD

Another renowned method of describing and computing an experience curve is the Crawford Method. In contrast to Wright, Crawford held that as quantity doubles, direct labor hours *per unit* (not cumulative average hours) decreases at constant rate. This concept may be expressed by the following formula:

$$T_u = T_1 X^{-K}$$

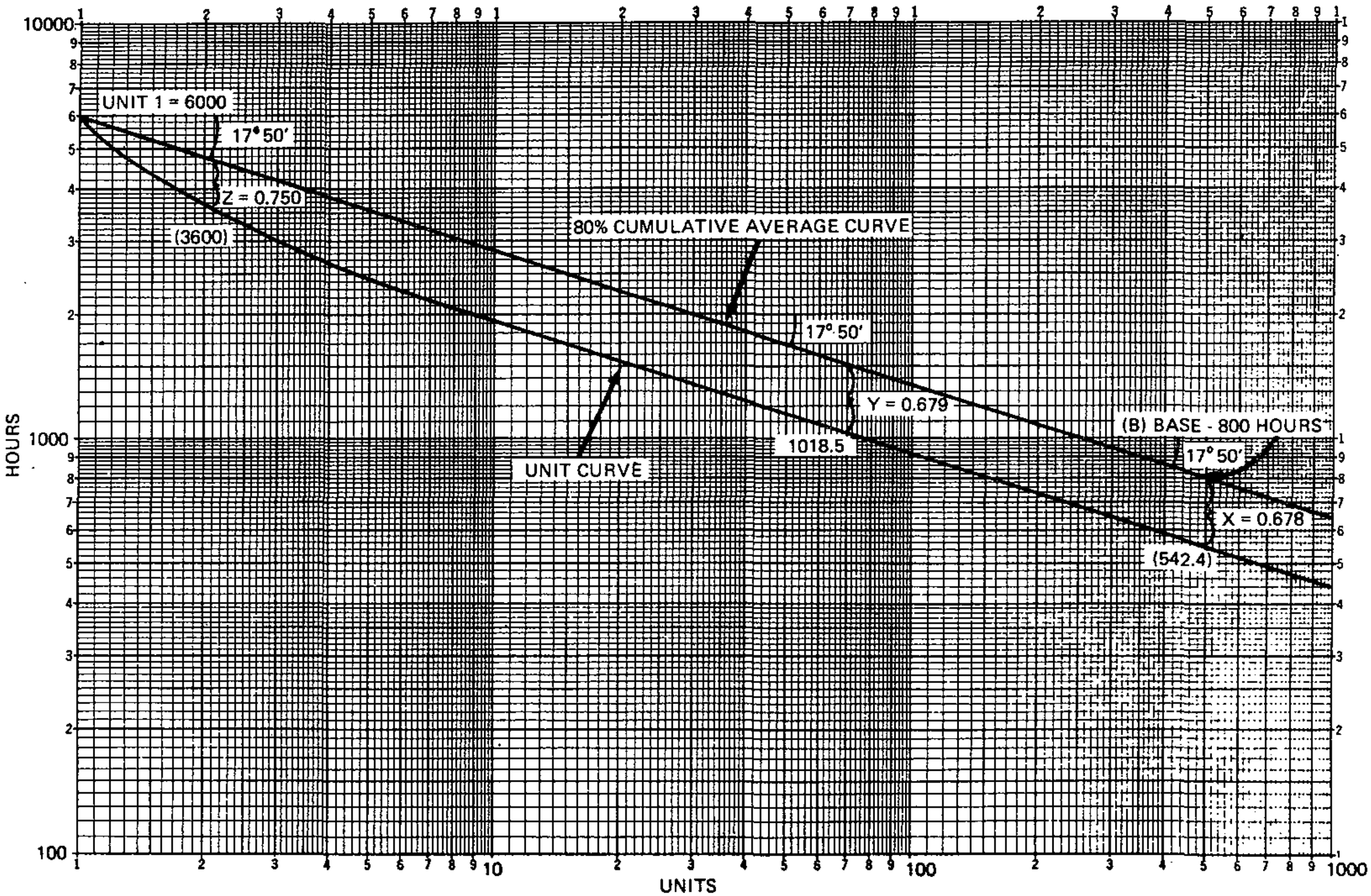


Figure A-10. Unit Curve Constructed from a Base Point (Cumulative Average for 500 Units Equals 800 Man-Hours)

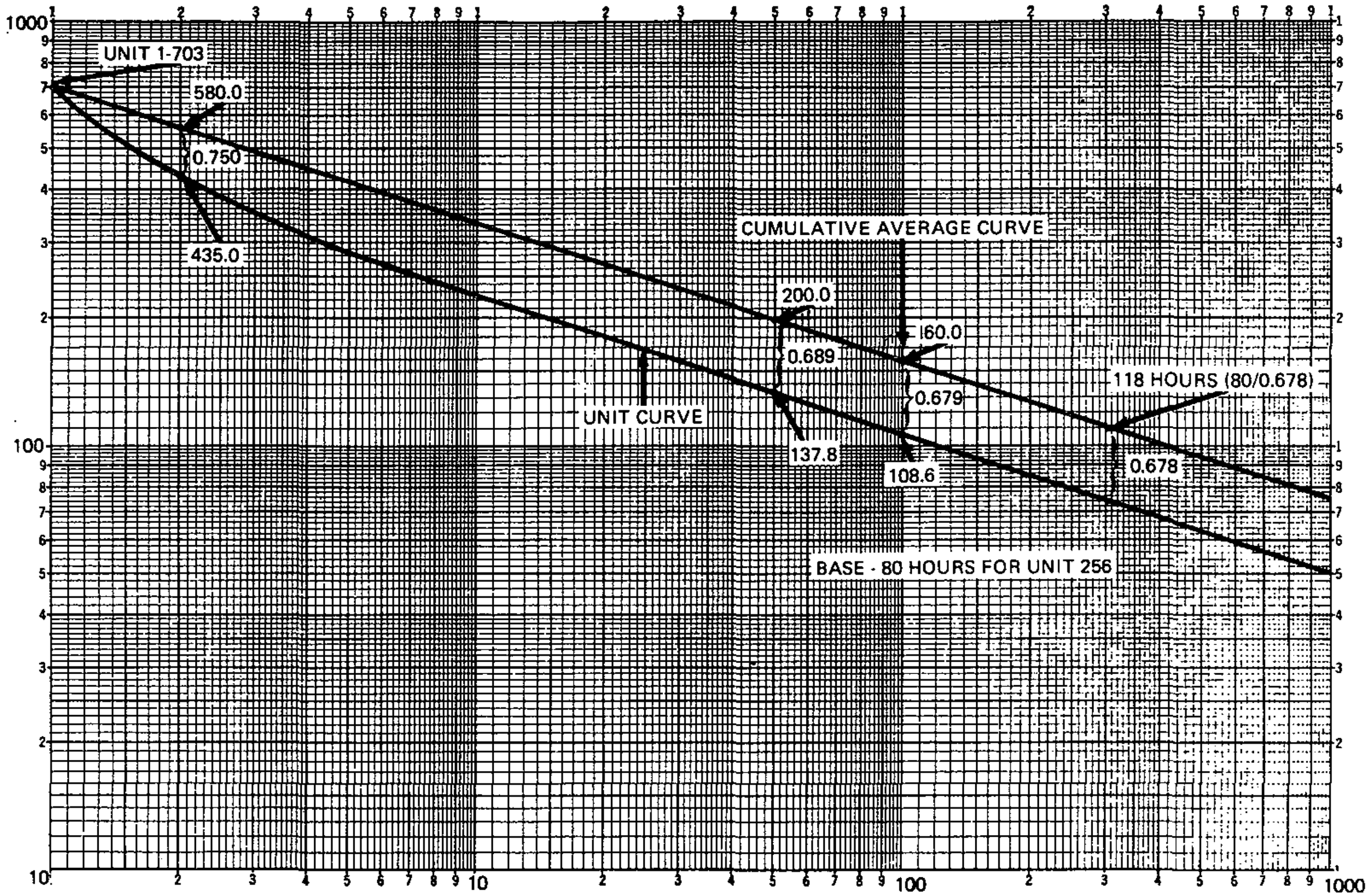


Figure A-11. Cumulative Average and Unit Curves Constructed from Hours for a Specific Unit when:

T_u = the total direct labor hours used to complete any specific unit

T_1 = the direct labor hours for the first unit (unit one)

X = the number of completed units

-K = the slope of the experience curve

Crawford proposed that the unit curve is indicative of the "experience" phenomenon rather than the cumulative average curve. He did, however, develop a cumulative average formula and a cumulative total formula as well as the asymptotic functions for these two relationships. Table A-5 reveals a significant difference between the Wright and Crawford methods in computing either the cumulative average cost or the final unit cost.

Table A-5. Comparison of the Wright Method with the Crawford Method for an 80 Percent Experience Curve (Unit One Common to Both)

	Wright		Crawford	
Unit	Unit Curve	Cumulative Curve	Unit Curve	Cumulative Curve
1	1000	1000	1000	1000
2	600	800	800	900
3	506	702	702	833
4	454	640	640	785
5	418	596	596	747
7	371	534	534	691
10	329	477	477	632
20	261	381	381	524
30	228	335	335	467
50	193	284	284	402
100	154	227	227	327
500	92	135	135	199
1000	73	108	108	159

Regardless of where a decimal point is placed, the differences when comparing either unit curves or cumulative average curves are apparent. As the slope of the curve changes, so does the percent difference between the ultimate cost; for example, with an 80 percent slope, the 100th unit cost using Wright is approximately 32 percent less than the 100th unit cost using Crawford, while the same relationship in cumulative average costs is approximately 31 percent.

With a 90 percent slope, at unit 100 the unit cost percentage difference is only approximately 15 percent and the cumulative average cost percentage difference is only approximately 14 percent. Although the drop in percentage difference is significant, even at a 90 percent experience curve there is still a great difference between the ultimate result obtained by employing one method as opposed to the other.

Figure A-12, utilizing data from table A-5, graphically illustrates the difference between the two methods. Note that the Wright cumulative average curve and the Crawford unit curve are identical. The differences become apparent when examining the relationship between unit curves and cumulative average curves. In both table A-5 and figure A-12 unit one is common to both methods.

On the other hand, if a common amount for unit 1,000 is assumed, the reverse is true: the differences will become increasingly significant as unit one is approached. The data in table A-6 and their graphic presentation in figure A-13 illustrate this point.

Table A-6. Comparison of Wright Method with the Crawford Method with an 80 Percent Experience Curve (Unit 1,000 Cumulative Average Common to Both)

	Wright		Crawford	
Unit	Unit Curve	Cumulative Curve	Unit Curve	Cumulative Curve
1	1000	1000	679	679
2	600	800	543	611
3	506	702	477	566
4	454	640	435	533
5	418	596	405	507
7	371	534	363	469
10	329	477	324	429
20	261	381	259	356
30	228	335	227	317
50	193	284	193	273
100	154	227	154	222
500	92	135	92	135
1000	73	108	73	108

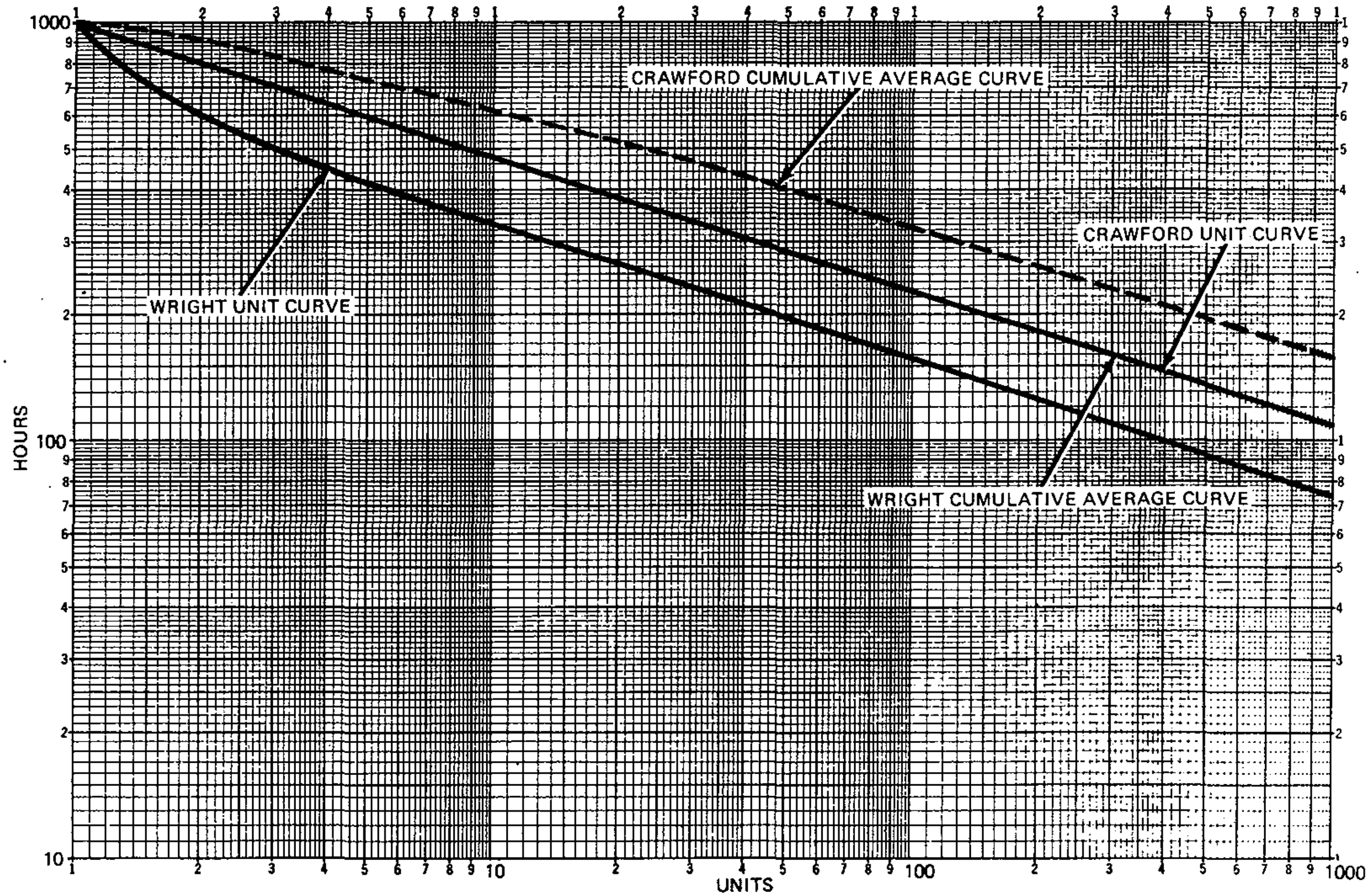


Figure A-12. Comparison of Wright Method with Crawford Method
(Data from Table A-5)

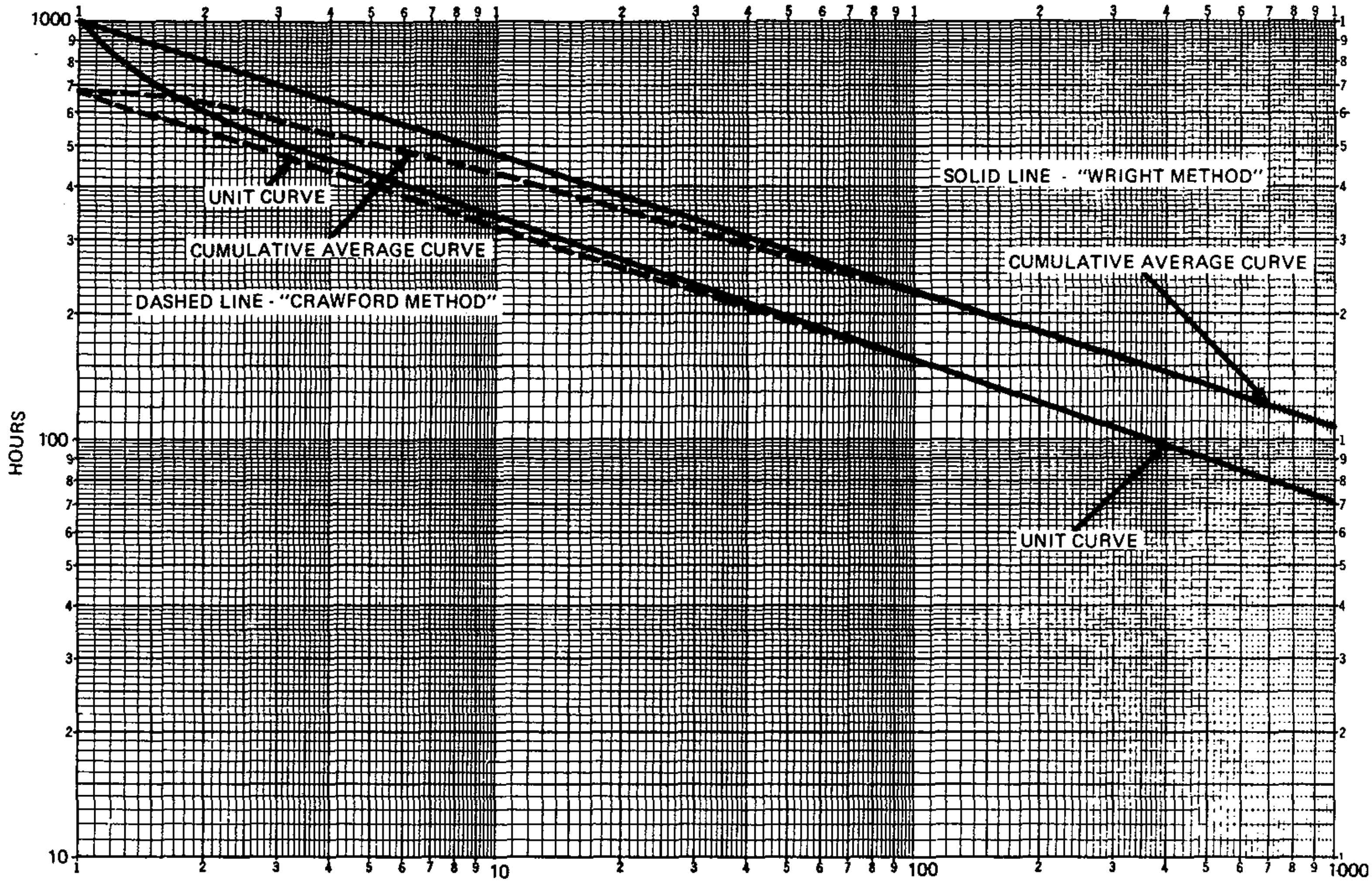


Figure A-13. Comparison of Wright Method with Crawford Method Using an 80 Percent Cumulative Average Curve (Data from Table A-6)

WRIGHT AND CRAWFORD PLOTTING CONSIDERATIONS

WRIGHT METHOD

Actual cumulative average data may be derived by two basic methods:

- Actual unit data are accumulated by individual unit, the actual cumulative total is computed by summing the unit hours through the specified unit and the cumulative average is then computed by dividing the cumulative total by the desired cumulative unit number.

- Actual lot data are accumulated representing the man-hours (or cost) expended to produce a specified lot size. These data may be arranged in such a manner that it becomes a simple task to plot both the cumulative average curve and the unit curve. Table A-7 shows an example of this data arrangement.

Table A-7. Cumulative Average Hours Derived from Actual Lot Data

Lot No.	Qty per Lot	Avg Hrs per Unit	Total Hrs per Lot	Total Cum Hrs	Cumulative Quantity	Cumulative Avg Hrs
1	8	2400	19200	19200	8	2400
2	24	1300	31200	50400	32	1575
3	30	1050	31500	81900	62	1321
4	38	800	30400	112300	100	1123
5	40	750	30000	142300	140	1016
6	40	850	34000	176300	180	979
7	46	800	36800	213100	226	943
8	54	650	35100	248200	280	886
9	48	600	28800	277000	328	845

From the data in table A-6, the slope of the curve can be established by dividing the cumulative average hours through the last unit by the cumulative average hours for half the cumulative quantity. The cumulative average for half the quantity of 328 is 164. This is between the cumulative average amounts for 140 and 180 units, respectively; between 1,016 hours and 979 hours. By interpolation the cumulative average at unit 164 can be determined. This is 979 plus (16/40) x 37, which is 14.8 for a total of 993.8 hours, rounded to 994 hours. The cumulative average at 328, 845 hours, can be divided by the cumulative average at 164 (993.8 hours) to determine a slope of 85.03 percent. For most purposes, this can be rounded off to 85 percent.

Figures A-14 and A-15 illustrate both the actual data plotted and the "theoretical" curves derived as a result of calculations made from data in table A-7. Because plotting the data did not result in a smooth curve, a theoretical experience curve has been developed in order to aid the user when extrapolation is required. Not only are theoretical curves developed, a theoretical unit one is also determined. The "theoretical" 85 percent scope illustrated in figure A-15 considered only two points of actual data (selected by "eyeballing" figure A-14). For greater accuracy several data points should be considered along with applicable statistical techniques (e.g., least squares method).

Both the theoretical cumulative average curve and the theoretical unit curve in figure A-15 have been developed with the aid of experience curve tables in table A-8. The use of these tables eliminates the necessity for most of the mathematical calculations in curve construction, provides greater accuracy than the calculations, and reduces overall problem-solving time. The tables used for this example are based on an 85 percent *cumulative average experience curve* (Wright Method).* Three curves are tabulated through unit 500--the unit curve (U/C), the cumulative average curve (C/A), and the cumulative total curve (C/T).

Although table A-8 addresses only units one through 100 and 301 through 500 it is a simple matter to find the cumulative average value, for a specified slope, for cumulative units beyond the limits of this table. For example, if the value for 1,000 on an 85 percent curve is desired, the value for unit 500 (0.2329) could be multiplied by 0.85 and the answer would be 0.1980. For unit 2,000, the value for 1,000 (0.1980) can be multiplied by 0.85; the product would be 0.1683. This method employs the principle that as the quantity doubles, the cumulative average value decreases by a constant amount, in this case 15 percent.

If the desired value is 1,536, then because half this amount does not fall within the limits of the table (768) and one-fourth does (384), the value for 384 cumulative units (0.2477) can be multiplied by 0.85 to find the value for 768 units (0.2105). This in turn can be multiplied by 0.85 to arrive at the value for 1,536 units (0.2105 x 0.85 = 0.1789). Although this method appears to be tedious, it circumvents the need for using logarithmic tables to solve the equation $TA = T_1X^{-K}$. If the tables are available and only two to three calculations are required, this method should provide an expedient solution.

The cumulative total can be determined by multiplying the calculated cumulative average value by the cumulating units. For example, if the cumulative total for 950 units based on an 85 percent cumulative average

*Additional curves are available and generally start at a 70 percent slope and include units one through 1,000. Because all published tables are similar, caution should be exercised when selecting the desired set.

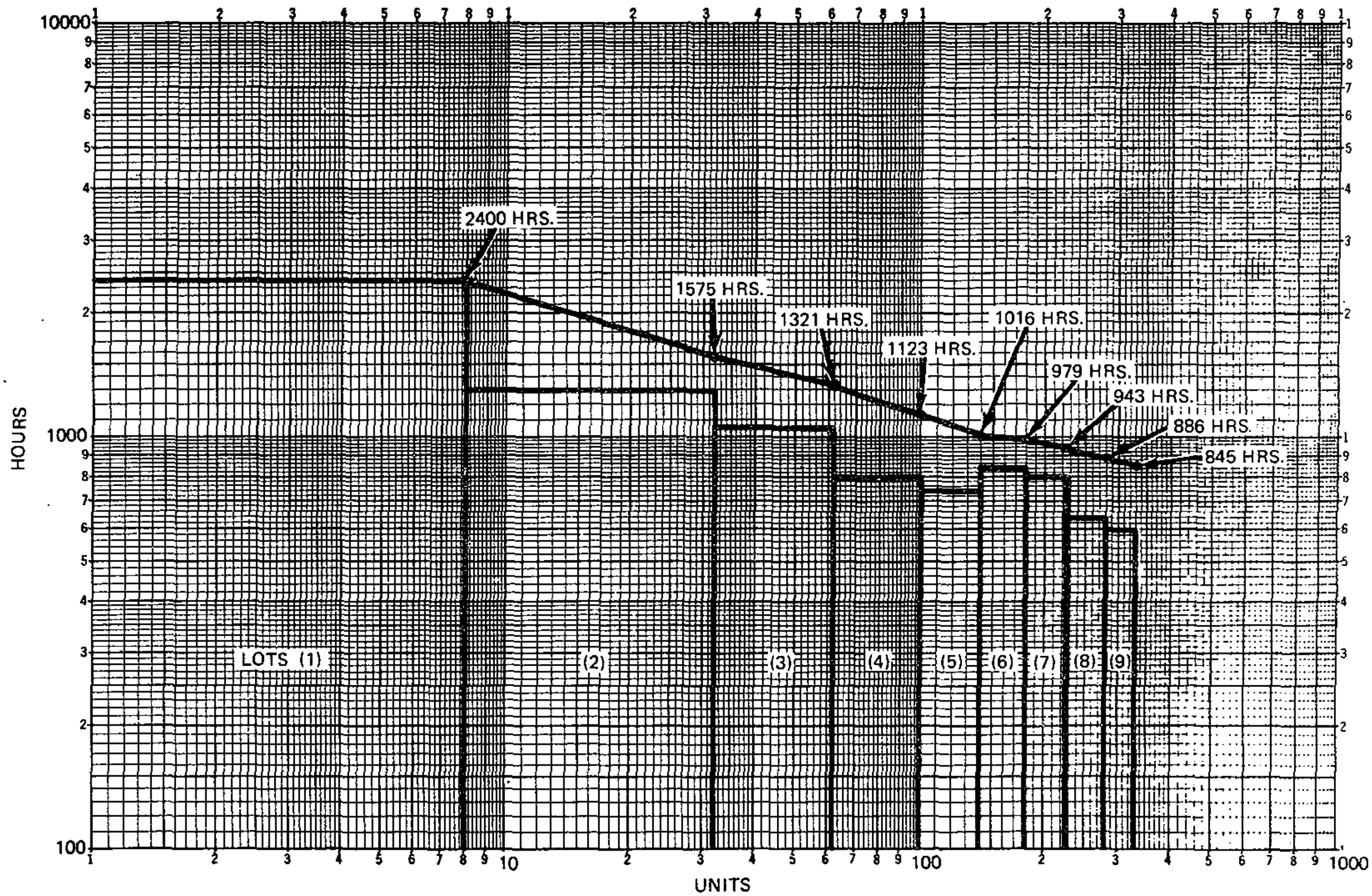


Figure A-14. Actual Lot Data Extracted from Table A-7

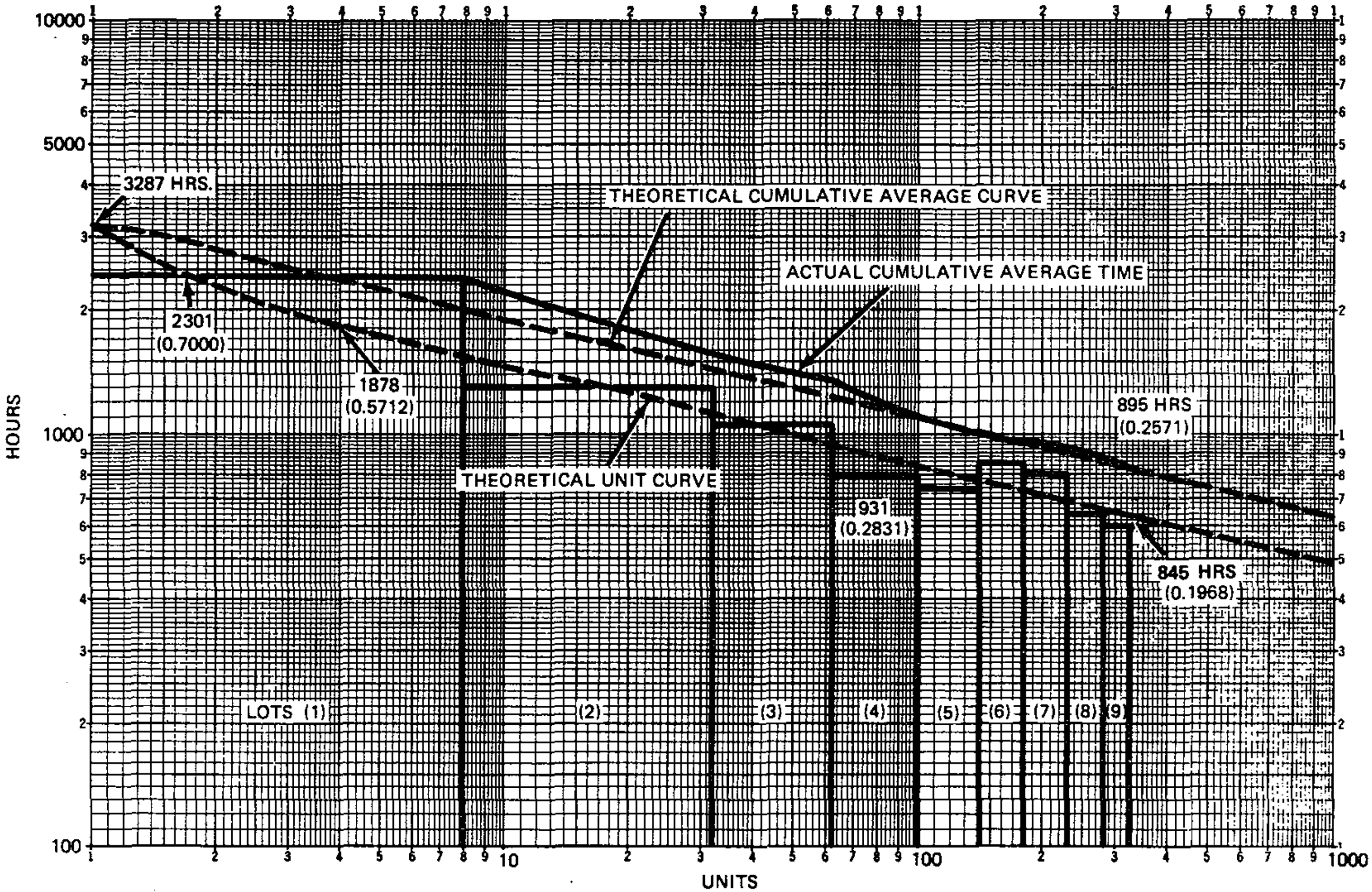


Figure A-15. "Smoothing" Data into Curves (Data from Table A-7)

Table A-8. Eighty-Five Percent Experience Curve--Wright Method

Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)	Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)
1	1.0000	1.0000	1.0000	29	13.1678	.3490	.4540
2	1.7000	.7000	.8500	30	13.5141	.3462	.4504
3	2.3187	.6187	.7729	31	13.8576	.3435	.4470
4	2.8900	.5712	.7225	32	14.1985	.3409	.4437
5	3.4283	.5383	.6856	33	14.5370	.3384	.4405
6	3.9418	.5135	.6569	34	14.8730	.3360	.4374
7	4.4355	.4937	.6336	35	15.2067	.3337	.4344
8	4.9129	.4774	.6141	36	15.5383	.3315	.4316
9	5.3765	.4635	.5973	37	15.8676	.3293	.4288
10	5.8282	.4516	.5828	38	16.1949	.3272	.4261
11	6.2693	.4411	.5699	39	16.5201	.3252	.4235
12	6.7011	.4318	.3584	40	16.8435	.3233	.4210
13	7.1246	.4234	.5480	41	17.1649	.3214	.4186
14	7.5405	.4158	.5386	42	17.4845	.3195	.4162
15	7.9494	.4059	.5299	43	17.8023	.3178	.4140
16	8.3520	.4026	.5220	44	18.1134	.3160	.4117
17	8.7488	.3967	.5146	45	18.4328	.3144	.4096
18	9.1401	.3913	.5077	46	18.7455	.3127	.4075
19	9.5264	.3862	.5013	47	19.0567	.3111	.4054
20	9.9079	.3815	.4953	48	19.3663	.3096	.4034
21	10.2850	.3770	.4897	49	19.6744	.3081	.4015
22	10.6578	.3728	.4844	50	19.9811	.3066	.3996
23	11.0268	.3689	.4794	51	20.2863	.3053	.3977
24	11.3919	.3651	.4746	52	20.5901	.3038	.3959
25	11.7536	.3616	.4701	53	20.8926	.3024	.3942
26	12.1118	.3582	.4658	54	21.1937	.3011	.3924
27	12.4669	.3550	.4617	55	21.4935	.2998	.3907
28	12.8188	.3519	.4578	56	21.7920	.2985	.3891

Table A-8. Eighty-Five Percent Experience Curve--Wright Method *(Continued)*

Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)	Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)
57	22.0893	.2972	.3875	82	29.1803	.2726	.3558
58	22.3854	.2960	.3859	83	29.4524	.2720	.3545
59	22.6802	.2948	.3844	84	29.7236	.2712	.3538
60	22.9739	.2936	.3828	85	29.9941	.2705	.3528
61	23.2665	.2925	.3814	86	30.2639	.2697	.3519
62	23.5579	.2914	.3799	87	30.5329	.2690	.3509
63	23.8483	.2903	.3785	88	30.8012	.2683	.3500
64	23.1375	.2892	.3771	89	31.0688	.2675	.3490
65	24.4257	.2881	.3757	90	31.3357	.2668	.3481
66	24.7129	.2871	.3744	91	31.6019	.2661	.3472
67	24.9990	.2861	.3731	92	31.8674	.2655	.3463
68	25.2841	.2851	.3718	93	32.1323	.2648	.3455
69	25.5683	.2841	.3705	94	32.3964	.2641	.3446
70	25.8515	.2831	.3693	95	32.6599	.2635	.3437
71	26.1337	.2822	.3680	96	32.9228	.2628	.3429
72	26.4151	.2813	.3668	97	33.1850	.2622	.3421
73	26.6955	.2804	.3656	98	33.4466	.2615	.3412
74	26.9750	.2795	.3645	99	33.7076	.2609	.3404
75	27.2536	.2786	.3633	100	33.9679	.2603	.3396
76	27.5313	.2777	.3622	301*	78.9639	.2009	.2623
77	27.8082	.2768	.3611	302	79.1646	.2007	.2621
78	28.0843	.2760	.3600	303	79.3652	.2005	.2619
79	28.3595	.2752	.3559	304	79.5656	.2004	.2617
80	28.6339	.2744	.3579	305	79.7659	.2002	.2615
81	28.8075	.2736	.3568	306	79.9661	.2001	.2613

*Data for units 101 through 300, which are not included in this table, are available to the public through many publications on experience curves (see the bibliography).

Table A-8. Eighty-Five Percent Experience Curve--Wright Method *(Continued)*

Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)	Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)
307	80.1660	.1999	.2611	335	85.7056	.1959	.2558
308	80.3659	.1998	.2609	336	85.9014	.1957	.2556
309	80.5655	.1996	.2607	337	86.0970	.1956	.2554
310	80.7651	.1995	.2605	338	86.2925	.1955	.2553
311	80.9644	.1993	.2603	339	86.4879	.1953	.2551
312	81.1637	.1992	.2601	340	86.6831	.1952	.2549
313	81.3627	.1990	.2599	341	86.8783	.1951	.2547
314	81.5616	.1989	.2597	342	87.0732	.1949	.2546
315	81.7604	.1987	.2595	343	87.2681	.1948	.2544
316	81.9593	.1986	.2593	344	87.4628	.1947	.2542
317	82.1575	.1984	.2591	345	87.6573	.1945	.2540
318	82.3559	.1983	.2589	346	87.8518	.1944	.2539
319	82.5540	.1981	.2587	347	88.0461	.1943	.2537
320	82.7521	.1980	.2586	348	88.2403	.1941	.2535
321	82.9500	.1978	.2584	349	88.4343	.1940	.2533
322	83.1477	.1977	.2582	350	88.6282	.1939	.2532
323	83.3453	.1976	.2580	351	88.8220	.1937	.2530
324	83.5428	.1974	.2578	352	89.0157	.1936	.2528
325	83.7401	.1973	.2576	353	89.2092	.1935	.2527
326	83.9373	.1971	.2574	354	89.4026	.1934	.2525
327	84.1343	.1970	.2572	355	89.5959	.1932	.2523
328	84.3312	.1968	.2571	356	89.7890	.1931	.2522
329	84.5280	.1967	.2569	357	89.9820	.1930	.2520
330	84.7246	.1966	.2567	358	90.1749	.1928	.2518
331	84.9211	.1964	.2565	359	90.3677	.1927	.2517
332	85.1175	.1963	.2563	360	90.5603	.1926	.2515
333	85.3136	.1961	.2561	361	90.7528	.1925	.2513
334	85.5097	.1960	.2560	362	90.9452	.1923	.2512

Table A-8. Eighty-Five Percent Experience Curve--Wright Method *(Continued)*

Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)	Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)
363	91.1375	.1922	.2510	391	96.4719	.1889	.2467
364	91.3296	.1921	.2509	392	96.6607	.1888	.2465
365	91.5216	.1920	.2507	393	96.8495	.1887	.2464
366	91.7135	.1918	.2505	394	97.0381	.1885	.2462
367	91.9053	.1917	.2504	395	97.2265	.1884	.2461
368	92.0970	.1916	.2502	396	97.4149	.1883	.2459
369	92.2885	.1915	.2501	397	97.6032	.1882	.2458
370	92.4799	.1914	.2499	398	97.7913	.1881	.2457
371	92.6712	.1912	.2497	399	97.9794	.1880	.2455
372	92.8623	.1911	.2496	400	98.1673	.1879	.2454
373	93.0534	.1910	.2494	401	98.3551	.1878	.2452
374	93.2443	.1909	.2493	402	98.5428	.1877	.2451
375	93.4351	.1908	.2491	403	98.7304	.1876	.2449
376	93.6258	.1906	.2490	404	98.9179	.1874	.2448
377	93.8163	.1905	.2488	405	99.1053	.1873	.2447
378	94.0063	.1904	.2486	406	99.2926	.1872	.2445
379	94.1971	.1903	.2485	407	99.4798	.1871	.2444
380	94.3873	.1902	.2483	408	99.6668	.1870	.2442
381	94.5774	.1900	.2482	409	99.8538	.1869	.2441
382	94.7674	.1899	.2480	410	100.0406	.1868	.2440
383	94.9572	.1898	.2479	411	100.2274	.1867	.2438
384	95.1470	.1897	.2477	412	100.4140	.1866	.2437
385	95.3366	.1896	.2476	413	100.6008	.1865	.2435
386	95.5261	.1895	.2474	414	100.7869	.1864	.2434
387	95.7155	.1893	.2473	415	100.9733	.1863	.2433
388	95.9048	.1892	.2471	416	101.1595	.1862	.2431
389	96.0939	.1891	.2470	417	101.3456	.1861	.2430
390	96.2830	.1890	.2468	418	101.5316	.1859	.2428

Table A-8. Eighty-Five Percent Experience Curve--Wright Method *(Continued)*

Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)	Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)
419	101.7175	.1858	.2427	447	106.8814	.1830	.2391
420	101.9032	.1857	.2426	448	107.0644	.1829	.2389
421	102.0889	.1856	.2424	449	107.2473	.1829	.2388
422	102.2745	.1855	.2423	450	107.4301	.1828	.2387
423	102.4600	.1854	.2422	451	107.6128	.1827	.2386
424	102.6454	.1853	.2420	452	107.7954	.1826	.2384
425	102.8307	.1852	.2419	453	107.9779	.1825	.2383
426	103.0158	.1851	.2418	454	108.1604	.1824	.2382
427	103.2009	.1850	.2416	455	108.3427	.1823	.2381
428	103.3859	.1849	.2415	456	108.5249	.1822	.2379
429	103.5707	.1848	.2414	457	108.7071	.1821	.2378
430	103.7555	.1847	.2412	458	108.8891	.1820	.2377
431	103.9402	.1846	.2411	459	109.0711	.1819	.2376
432	104.1247	.1845	.2410	460	109.2529	.1818	.2375
433	104.3092	.1844	.2408	461	109.4347	.1817	.2373
434	104.4936	.1843	.2407	462	109.6164	.1816	.2372
435	104.6778	.1842	.2406	463	109.7980	.1815	.2371
436	104.8620	.1841	.2405	464	109.9795	.1814	.2370
437	105.0461	.1840	.2403	465	110.1609	.1814	.2369
438	105.2300	.1839	.2402	466	110.3422	.1813	.2367
439	105.4139	.1838	.2401	467	110.5234	.1812	.2366
440	105.5977	.1837	.2399	468	110.7046	.1811	.2365
441	105.7814	.1836	.2398	469	110.8856	.1810	.2364
442	105.9646	.1835	.2397	470	111.0666	.1809	.2363
443	106.1484	.1834	.2396	471	111.2474	.1808	.2361
444	106.3318	.1833	.2394	472	111.4282	.1807	.2360
445	106.5151	.1832	.2393	473	111.6089	.1806	.2359
446	106.6983	.1831	.2392	474	111.7895	.1805	.2358

Table A-8. Eighty-Five Percent Experience Curve--Wright Method *(Continued)*

Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)	Unit	Cumulative Total Value (C/T)	Unit Curve Value (U/C)	Cumulative Average Value (C/A)
475	111.9700	.1805	.2357	488	114.3084	.1793	.2342
476	112.1504	.1804	.2356	489	114.4877	.1792	.2341
477	112.3307	.1803	.2354	490	114.6669	.1791	.2340
478	112.5109	.1802	.2353	491	114.8460	.1791	.2339
479	112.6911	.1801	.2352	492	115.0250	.1790	.2337
480	112.8711	.1800	.2351	493	115.2040	.1789	.2336
481	113.0511	.1799	.2350	494	115.3828	.1788	.2335
482	113.2310	.1790	.2349	495	115.5616	.1787	.2334
483	113.4108	.1797	.2348	496	115.7403	.1786	.2333
484	113.5905	.1797	.2346	497	115.9188	.1785	.2332
485	113.7701	.1796	.2345	498	116.0974	.1785	.2331
486	113.9496	.1795	.2344	499	116.2758	.1784	.2330
487	114.1291	.1794	.2343	500	116.4541	.1783	.2329

curve is the desired value; by dividing 950 by two a number within the limits of the table (425) can be found. The cumulative average value of 425 is 0.2419. By multiplying 0.2419 by 0.85 the cumulative average for 950 units is 0.2056. By multiplying 0.2056 by 950 the cumulative total can be obtained (195.3200). Note that the accuracy of this calculation depends on the number of decimal places in the cumulative average value.

Using the relationships between curves (see table A-4), the unit cost for unit 1,000 can be calculated even if the tables do not include values beyond 500. The cumulative average for unit 1,000 is 0.1980 (0.2329 times 0.85). This value is multiplied by the appropriate relationship from table A-4 (0.766), and the product is the unit value for unit 1,000 (1516.7).

Another method for determining the cumulative average value for a unit not in the range of the tables is shown below:

Find the cumulative average hours through the 5,000th unit using a unit one value of 2,000 hours and an 85 percent slope.

Cumulative average table value, unit 500	.2329
Extension factor for 85 percent slope (table A-9)	x .5828204
Cumulative average table value, unit 5000	.1357389
Unit one	x 2000
Cumulative average value through unit 5000	271.478

An 85 percent slope has been calculated from the data in table A-7; by dividing the last known cumulative average hour value by the corresponding value for those cumulative units (328), obtained from the experience curve tables (845/0.2571), the theoretical unit one value of 3286.7 man-hours can be obtained. These two points then can be connected to form the theoretical cumulative average curve. Using the experience curve tables, the value on the theoretical unit curve for the last unit (328) can be determined by multiplying the unit one value by the unit curve value for unit 328 (0.1968), or 3,287 X 0.1968 = 647. The is also borne out by multiplying the cumulative average value by the relation between curves in table A-4 (845 x 0.766 = 647). Continued use of these experience curve tables will provide a sufficient number of values with which a corresponding unit curve may be constructed.

CRAWFORD METHOD

This method basically relies on individual unit data plotted separately and fitted into a trend line (curve). The accepted technique for fitting a straight line to a set of data in such a way that it represents the best "fit" of any straight line associated with the data is the method of curve fitting known as the "least squares method." The reason this straight line is the best possible fit is because mathematically the sum of the squares of the deviations of the actual data points from the

Table A-9. Experience Curve Extension Factors*

Slope (%)	Extension Factor	Slope (%)	Extension Factor
50	.1000000	75	.3845586
51	.1067995	76	.4018568
52	.1139157	77	.4196917
53	.1213568	78	.4380726
54	.1291312	79	.4570088
55	.1372472	80	.4765099
56	.1457131	81	.4965852
57	.1545375	82	.5172444
58	.1637287	83	.5384969
59	.1732953	84	.5603524
60	.1832460	85	.5828204
61	.1935892	86	.6059106
62	.2043338	87	.6296328
63	.2154883	88	.6539965
64	.2270617	89	.6790117
65	.2390626	90	.7046880
66	.2515000	91	.7310355
67	.2643827	92	.7580638
68	.2777197	93	.7857830
69	.2915199	94	.8142029
70	.3057925	95	.8433336
71	.3205464	96	.8731851
72	.3357908	97	.9037673
73	.3515348	98	.9350905
74	.3677877	99	.9671647

*The Extension Factors multiplied by any cumulative average value will give the cumulative average value for a unit that is ten times as large.

straight line is forced to be its lowest possible value.* Therefore, when an experience curve is calculated from actual data points, the resulting curve is the one that best represents the data. In addition, if the points were so scattered that no trend can be discerned one of the several statistical measures would have to be used.

However, when data are not available by individual units but available only by lot, the representative unit of the lot must be determined. This unit also represents the average unit cost of the lot. Therefore, the algebraic lot midpoint must be calculated. The man-hours (or cost) of this unit when multiplied by the number of units in the lot will result in the total cost of the lot. Algebraic lot midpoints can be calculated by the formula:

$$M = \left[\frac{L \cdot (1+K)}{N_2^{1+K} - N_1^{1+K}} \right]^{\frac{-1}{K}}$$

when:

- M = algebraic lot mid-point
- N_1 = first unit in lot minus 1/2
- N_2 = last unit in lot plus 1/2
- L = number of units in the lot
- K = exponent of the slope

This assumes that at least an estimate of the slope can be made through a rough plot of the *arithmetic* lot midpoints. The arithmetic lot midpoint is the arithmetical center of the lot (for example, the lot of 100 units beginning with unit 51 and ending with 150; arithmetical lot midpoint = (51 + 150) ÷ 2 = 100.5). This is not to be confused with the average unit man-hours (or cost) of a lot, which is the total man-hours (or cost) of the lot divided by the number of units in the lot (for example, 1,000 man-hours expended to produce a lot of eight units; the average man-hours per unit for this lot equals 125 man-hours).

There is a "quick method" for calculating approximate algebraic lot midpoints for general use without using the aforementioned formula. By following the procedure shown below and using experience curve tables, the algebraic lot midpoint can readily be obtained, assuming the slope is known.

Procedure:

- Locate the slope of the experience curve in the tables (e.g. table A-8, 85 percent).

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*This technique is not unique to the Crawford Method and a complete explanation may be found in most standard textbooks on statistical techniques.

• Locate the cumulative total value for the last unit number of the lot.

• Locate the cumulative total value for *one less than the first* unit number in the lot.

• Subtract this value from the cumulative total value of the total value of the last unit in the lot and divide the result by the *total* number of units in the lot.

• Locate this value (quotient) in the unit curve column for the same slope.

• Having located the value *that is closest*, look across to the unit number which corresponds to this value. This unit number is the algebraic or "true" midpoint of the lot.

Example:

Find the approximate algebraic (true) lot midpoint of a lot whose unit range is #101-#500, using an 85 percent experience curve.

Cumulative total value--unit 500	116.4541
Cumulative total value--unit 100	- 33.9679
	82.4862
Total number of units in lot	÷ 400
Unit value for true lot midpoint	.2062
True lot midpoint	269

ADDITIONAL HYPOTHESES

In addition to the two "brand-name" methods, a number of articles and reports have been written on the subject of experience curves. Significant excerpts of several of these works are presented by Vincent Colasuono, *An Analysis of Progress Curve Conceptual Advances and Progress Curve Uses, Since 1956*. Referenced works include: A. Aichian, H. Asher, A. B. Berghell, G. W. Carr, Crawford-Strauss, P. Guibert, W. Z. Hirsch, K. A. Middleton, and the Stanford-B Curve.

Wright himself said that the total cost curve changes its slope at units 100, 1,000, and 10,000 when material and overhead are added to direct labor. This would indicate that he considered the function as possessing four linear segments instead of the single linear segment commonly conceived of as the "Wright Method." (The development of curves is discussed later under the subject heading "Selection of Experience Curve Ingredients.")

A review of these works will reveal that although the basic concept of man-hours (or cost) decreasing as the number of units produced increases is common to all methods, there are more than two mathematical approaches.

USES OF EXPERIENCE CURVES

The experience curve is one of a number of management information tools, the major application being in the areas of forecasting and estimating. Because of the empirical nature of the data, the experience curve is considered by many experts as merely a byproduct of normal production reporting data, and the data remain in a semidormant (i.e., raw, not plotted) state, not being fully utilized in the aforementioned areas. For other experts, the experience curve plays a significant, if not the most important, role in forecasting an attainable rate of progress or improvement, in aiding management in controlling production activities to the forecasted levels, and in providing a consistent measure for estimating costs based on these goals (which were, in fact, based on experience).

The use of experience curves is not limited to its measure of labor, direct or otherwise; some of its other important applications are discussed below. For further applications you are referred to the bibliography.

MANPOWER LOADING

The experience curve indicates the expected rate of improvement (or increasing rate of output) for a given number of employees. Therefore, in a given process, to meet a specific delivery date, manpower requirements in terms of total numbers and number of shifts to be worked interfaced with available equipment and floor space can be determined. When sequential processes are required, the availability of skills and equipment can be scheduled even if experience curves are different for each process. Assuming a fixed delivery scheduled for the completed product requiring three sequential processes of fabrication, assembly, and test, the individual manpower requirements for each process can be ascertained by "backing up" from the final delivery date.

MATERIAL PLANNING

Production schedules based on an analysis of experience curves enable optimum material planning by providing procurement personnel with the necessary information for acquiring components in sufficient quantity, at the right time and at minimum cost. This in turn can decrease the contractor's total-inventory-on-hand position, releasing valuable dollars for alternative uses, without jeopardizing production schedules. An additional savings of reduced storekeeping space and associated handling costs also can be realized.

TOOLING AND EQUIPMENT

Because wide fluctuations in operation time occur as a result of the phenomenon inherent in the experience curve concept, the interface between delivery dates and tooling and equipment is significant. Adherence to fixed delivery requirements may necessitate duplicate production runs requiring finite scheduling of available tooling and equipment. Detailed analysis of the applicable experience curves can assist in these projections.

INTERNAL COST CONTROL

Because initial experience curves should be developed from historical data, it can be expected that the actual data for similar situations will follow the same general trend. Yet, if this concept were strictly adhered to the question of whether the current curve follows the experience or whether the experience follows the curve might remain unanswered. Management, through the application of experience curves, can detect if a stagnation in improvement has set in. IT is unlikely that current production will exactly track an existing experience curve, and if it does, the probabilities are that production personnel are attempting to use the initial curve as a production standard of sorts. The curve, of course, should follow the experience, and management should expect improvement reflected by a reduction in the slope of the curve.

OVERALL OBJECTIVE POSITION

An analysis of experience curve data reveals that there is a relationship between the percentage of completion of an order or production run and the equivalent man-hours (or cost) expended through a given unit. The following hypothetical case illustrates this relationship.

Given: (1) A unit one of 1,000, (2) an 85 percent cumulative average curve (Wright Method), (3) a lot or order size of 100, and (4) Table A-8.

Problem: Determine percentage of man-hours (or cost) expended through unit ten.

Solution: (1) Identify cumulative total for total order or production run (33968). (2) Identify cumulative total for desired unit (5,828). (3) Divide cumulative total for desired unit by cumulative total for total or production run (17.2 percent).

Therefore, with only 10% of the order or production run complete (100 divided by 10), 17.2 percent of the man-hours (or cost) have been expended. As the percentage of unit completion increases, the gap between the two percentages decreases (for example, 75 percent completion, 80.2 percent of the man-hours (or costs) will have been expended). When the order or production run is completed (100 percent), then 100.0 percent of the man-hours (or cost) will have been expended.

COMPARABILITY OF DATA

Earlier in this discussion, the point was raised that technology played a significant role in contributing to the controversial nature of this subject. The differences in terminology are a result, in part, of the different types of data used for establishing plotting values. Therefore, it is imperative to define the data input and specifically what it represents. As an illustration, the cost of tooling, methods engineering, and the like contribute to the overall reduction in cost and should be included in the calculation of an overall cost curve. But when measuring the experience curve of the direct production worker, these data should not be included in the values plotted for that experience curve. On the other hand, the cost incurred by the direct production worker could be included in an overall cost curve. As another example, material cost is certainly a cost to be included in the total cost picture, but inclusion of material cost data on the experience curve for the direct production worker can serve only to mislead--unless, of course, the desired result is to have the experience curve portray past experience for both direct production labor *and* material.

Taking this a step farther, a curve constructed with the first lot containing the cost of a total automobile, the second lot containing only the cost of the motor, and the third lot containing the cost of the entire automobile less the frame, would not likely be an accurate predictor of the cost of the ignition system. The experience curve can represent only what is put into it and is only as good as the management information from which it is constructed. Thus extreme care should be taken to ensure that the cost or man-hour input is reliable.

Another significant point about comparability of data is that for the curves to be representative of the entire picture, all of the comparable data involved must be represented. When plotting a point on a graph to construct an experience curve, both the "x" and "y" values must be known (that is, units and man-hours (or cost) must be known). If the man-hours (or cost) of an individual unit or lot was not available, the data point (y) could not be plotted; this would not alter the fact that the unit had been completed and must be accounted for in its proper sequence. (It is unlikely that the "x" value (unit or lot number) would not be known, including its respective position in sequence.)

OTHER CONSIDERATIONS FOR EXPERIENCE CURVE ACCURACY

Aside from the introduction of noncomparable data, which has been discussed, some of the other common accuracy considerations for developing an experience curve are:

• Accuracy with which historical data are accumulated. For example, a fluctuating labor classification system that frequently shifts the designation of workers between "direct" and "indirect/support" categories can add or subtract a worker's time from performance on any specified unit. By altering the classification of a worker or his job without necessarily changing the work, significant changes in the actual recorded hours per unit trend will occur. To illustrate, if seven men produce four units per 8-hour day, the average number of hours per unit is 14 hours per unit, [(7 x 8) ÷ 4 = 14 hours/unit]. Now suppose that one of the jobs is reclassified as "indirect." The worker does the same work, but his time is no longer calculated as "direct labor" and, hence, is not shown on the experience curve. The apparent improvement is 2 hours per unit [from (6 x 8) ÷ 4 = 12 hours/unit]. This appears to be a significant 30 percent reduction but is, in fact, no real improvement because total efficiency is the same.

• Production may be characterized by poor starting documentation. The first end items may be modified many times before they are acceptable; engineering specifications are modified after the fact to reflect changes made first on the hardware; also, many programs are put into production concurrently with development effort on identical hardware. It is not unusual to find hardware being produced simultaneously on both development and production contracts with the former effort far more costly than the latter effort. The whole approach results in extensive rework of previous efforts to make the end items perform to specification. Contractors must consider this as well as the likelihood of customer-imposed changes when determining their manpower requirements.

SELECTION OF EXPERIENCE CURVE INGREDIENTS

GENERAL APPROACH

Existing experience curves, by definition, reflect past experience. Trend lines are developed from accumulated data plotted on logarithmic paper (preferably) and "smoothed out" to portray the curve. The type of curve may represent one of several concepts (Wright, Crawford, Stanford-B, and so on). The data may have been accumulated by product, process, department, or by other functional or organizational segregations, depending on the needs of the user. But whichever experience curve concept or method of data accumulation is selected for use, based on suitability to the experience pattern, the data should be applied consistently in order to render meaningful information to management. Consistency in curve concept and data accumulation cannot be overemphasized because existing experience curves play a major role in determining the projected experience curve for a new item or product.

When selecting the proper curve for a new production item when only one point of data is available and the slope is unknown, the following, in decreasing order of magnitude, should be considered:

• Similarity between the new item and an item or items previously produced.

Physical comparisons
- Addition or deletion of processes and components
- Differences in material, if any
- Effect of engineering changes on items previously produced

Duration of time since a similar item was produced
- Condition of tooling and equipment
- Personnel turnover
- Changes in working conditions or morale

Other comparable factors between similar items
- Delivery schedules
- Availability of material and components
- Personnel turnover during production cycle of item previously produced
- Comparison of actual production data with previously extrapolated or theoretical curves to identify deviations.

It is feasible to assign weights to these factors as well as to any other factors that are of a comparable nature in an attempt to quantify differences between items. These factors are again historical in nature and only comparison of several existing curves and their actuals would reveal the relative importance of these factors.

• No similarity between the new item and an item or items previously produced.

• Base slope on internal manufacturer functional or organizational curve experience (example: departmental).

or

• Base slope on experience by another manufacturer for same or similar items.

or

• Base slope on intraindustry curves for comparability.

Obviously, as the alternatives decrease in order of magnitude the probability of attaining reasonable accuracy decreases proportionately. The question of availability of data, suggested above, must be raised.

If at least two points of data are available, the slope of the curve may be determined. Naturally the distance between these two points must be considered when evaluating the reliability of the slope. The availability of additional points of data will enhance the reliability of the curve. Regardless of the number of data points and the assumed reliability of the slope, comparisons with similar items are considered the most desirable approach and should be made whenever possible.

A value for unit one may be arrived at in one of two basic ways:

- Accumulation of data
- Statistical derivation

When production is under way, available data can be readily "plotted," and the curve may be extrapolated to a desired unit. However, if production has yet to be started, actual unit one data would not be available and a theoretical unit one value would have to be developed. This may be accomplished in one of two ways.

- Actual lot data (period values in a process cost system) can be plotted (see figures A-14 and A-15) if production is under way.

- Knowledge of both the slope and the point at which the curve and the labor standard value converge are known. In this case a unit one value can be determined. This is accomplished by dividing the labor standard by the appropriate unit value. For example, if the labor standard is 1 hour and the point of convergence is at unit 500, the theoretical unit one would be 4.29 hours (1.0 ÷ .2329) for an 85 percent slope (see table A-8).

TECHNICAL APPROACH

In addition to the general techniques mentioned, the following more sophisticated techniques may be used in selecting the key components of an experience curve.

- Gallagher (*Project Estimating by Engineering Methods*) Technique. This lists five elements that affect the selection of the slope.

- Rate of production
- Newness of the program
- Amount of repetitive elements
- Amount of hard or soft tools
- Type of work

Also considered are four elements that affect the unit one value.

- Newness of program
- Complexity

- Type of work
- Amount of hard or soft tools.

By applying graduated values to the elements of newness and complexity, a nomogram may be developed that will permit the derivation of a factor that represents the hours per standard hour at unit one. With this factor established, along with a prorated scale for rates of delivery, another nomogram may be developed to determine the correct slope.

- Relationships between the labor standard and the experience curve technique. This technique utilizes the contract labor standard with actual or historical experience curves. Although in theory the experience curve is asymtotic (that is, it approaches but never reaches zero), the realities of production dispute this theory. For example, assuming a unit one expenditure of 1,000 hours with 75 percent slope, the cumulative average value at unit 100,000 theoretically would be 8.41 hours; at unit 800,000 it would be 3.55 hours. It is highly unlikely that these decreases in hours expended will actually take place. (Somewhere between the unit one value and the unit 100,000 value is reality, where "learning" no longer occurs.)

In conclusion, with an understanding of labor standards it can be seen that at some point (depending on the slope) the experience curve value and the value of the standard converge. In fact, if the labor standard is representative of the classical "average performance," the experience curve should cross the horizontal line illustrating the standard value and continue its downward slope until such time when maximum performance, by definition, is reached. At this point the curve should "flatten out" despite the asymtotic theory. The point of convergence between the experience curve and standard (line) should be identified through an analysis of past history rather than arbitrary assumptions. Some attempts have been made to forecast this point of convergence (see chapter 7 of the *Industrial Engineering Handbook*, 3rd edition), but this applies only to worker learning and does not consider management innovations.

FOLLOW-ON ORDERS

Once the initial experience curve(s) have been developed for either the initial order or production run, the values through the last unit on the cumulative average and unit curves are discernible. Follow-on orders and continuations of production runs, which are considered extensions of the original orders or runs, are plotted as extensions on the appropriate curve. However, the cumulative average value through the final point of the extended curve is not the cumulative average for the follow-on portion of that curve. But it is, the cumulative average for both portions of the curve, assuming no break in production. Likewise, the last unit value for both portions of the unit curve would represent the last unit value for the combined curves.

If a value for the cumulative average portion of the follow-on order or production run is desired, then the technique in the following hypothetical case illustrated in figure A-16 should be employed.

Hypothetical Case

Problem:

(1) Unit one has a value of 1,000

(2) The slope is 80 percent (Wright Method)

(3) The initial order or production run is for 100 units

(4) The extension (no break in production) is for an additional 100 units

Solution:

(1) Construct cumulative average and unit curves through the 200th unit by any of the previously described methods. Use *3- by 3-cycle* logarithmic paper.

(2) Note the cumulative average value (227) and the unit curve value (154) for the 100th unit.

(3) Plot the cumulative total value for 100 units (227 x 100 = 22,700) and connect this point with the unit one value as a straight line to construct a cumulative total curve.

(4) Note the cumulative average value (182) and the unit curve value (123) for the 200th unit.

(5) Plot the cumulative total value for 200 units (182 x 200 = 36,400) and correct this point with the cumulative total value for 100 units as a straight line.

(6) Subtract the value for the cumulative total for 100 units from the cumulative total value for 200 units. The remainder is the cumulative total for the follow-on portion of the curve (36,400 - 22,700 = 13,700).

(7) Divide this remainder by the number of units in the follow-on portion to arrive the average value for the 100 follow-on units (13,700/100 = 137). This value will be located on the extended portion of the unit curve near the midpoint between the end of the initial unit curve for 100 units and the end of the extended unit curve totaling 200 units.

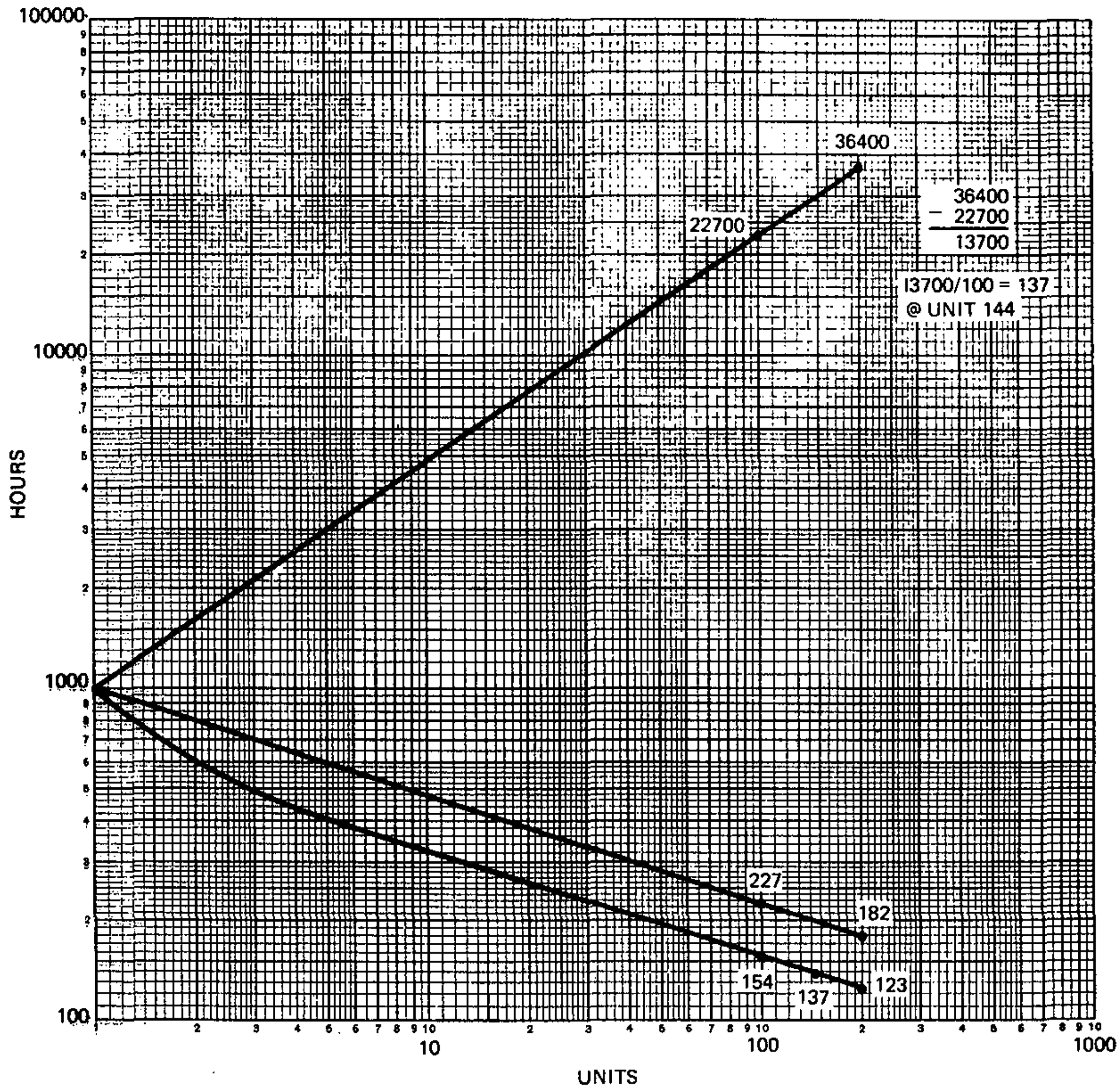

Figure A-16. Plotting the Cumulative Average Value for a Follow-on Order

PRODUCTION BREAKS

The production break is the time lapse between the completion of an order or production run for the manufacture of certain units of equipment and the commencement of a follow-on order or restart of a production run for identical units. This time lapse disrupts the continuous flow of production and constitutes a definite cost. The time lapse under discussion here pertains to significant periods of time (weeks and months) as opposed to the minutes or hours for personal allowances, machine delays, power failures, and the like.

It has been established that experience curves are:

- An expression of man-hours (or cost) reduction as a function of time

- Determined on the basis of empirical data

- The result of the contributions of various segments of the organization

Time or Cost Reduction

It is logical to assume that because the experience curve has a time/cost relationship, a production break will effect both time and cost. Therefore, the length of the production break becomes as significant as the length of the initial order or production run. Because the production break is quantifiable, the remaining factor to be determined is the cost of this lapse in production (that is, the additional cost incurred over and above that which would have been incurred had either the initial order or the production run been continued through the duration of the follow-on order or the restarted production run.

Empirical Data

When a manufacturer relies on experience curves as management information tools, it can be assumed that the necessary, accurate data for determining the initial curves have been accumulated, recorded, and properly validated. Therefore, if the manufacturer has experienced production breaks, the experience curve data for the orders (lots) or production runs involved should be available in such form that appropriate curves can be developed.

Contributory Factors

George Anderlohr, in the September 1969 issue of *Industrial Engineering*, suggests a method that assumes loss of learning is dependent on five factors:

(1) Production Personnel Learning. In this area, the physical loss of personnel, either through regular movement or layoff, must be determined. The company's personnel records can usually furnish evidence on which to establish this learning loss. The percentage of learning lost by the personnel retained on other plant projects must also be ascertained. These people will lose their physical dexterity and familiarity with the product, and the momentum of repetition.

(2) Supervisory Learning. Once again, a percentage of supervisory personnel will be lost as a result of regular movement. Management will make a greater effort to retain this higher caliber of personnel, so the physical loss, in the majority of cases, will be far less than in the area of production personnel. However, the supervisory personnel retained will lose their overall familiarity with the job, so that the guidance they can furnish will be reduced. In addition, because of the loss of production personnel, the supervisor will have no knowledge, so necessary in effective supervision, of the new hires and their individual personalities and capabilities.

(3) Continuity of Productivity. This relates to the physical positioning of the production line, the relationship of one work station to another, and the location of lighting, bins, parts, and tools within the work station. It also includes the position adjustment to optimize the individual needs. In addition, a major factor affecting this area is the balanced line or the work-in-process buildup. An example of this would be the fact that work station has completed its operations and released the part to work station three. Of all the elements of learning, the greatest initial loss is suffered in this area.

(4) Methods. This area is least affected by a production break. As long as the method sheets are kept on file, learning can never be completely lost. However, drastic revisions to the method sheets may be required as a result of a change from soft to hard tooling.

(5) Special Tooling. New and better tooling is a major contributor to learning. In relating loss in the tooling area to learning, the major factors are wear, physical misplacement, and breakage. An additional consideration must be the comparison of short run or so called soft tooling to long run or hard tooling, and the effect of the transition from soft to hard tooling.

In Anderlohr's hypothetical case, each of the five elements is assigned a weight of 20 percent as a starting standard, but he states that "refinement of the weight will be needed for different industries as well as for different companies, within the industries. To a large extent, this refinement depends on the relative skill of the production personnel. The engineering technician, for example, relies less on supervision methods, and special tooling than does the average assembler. This would be reflected in a difference of comparative weights." Furthermore, he added:

> Suppose a company produces 20 units of an item. The company's past experience indicates an improvement on the basis of an 85 percent learning curve (figure A-17). Production of the 20 units averages 495.5 hours per unit, with the first unit consuming 1,000 hours. Six months after the completion of the 20 units, a follow-on contract is received for 30 identical units. Learning is lost as follows:

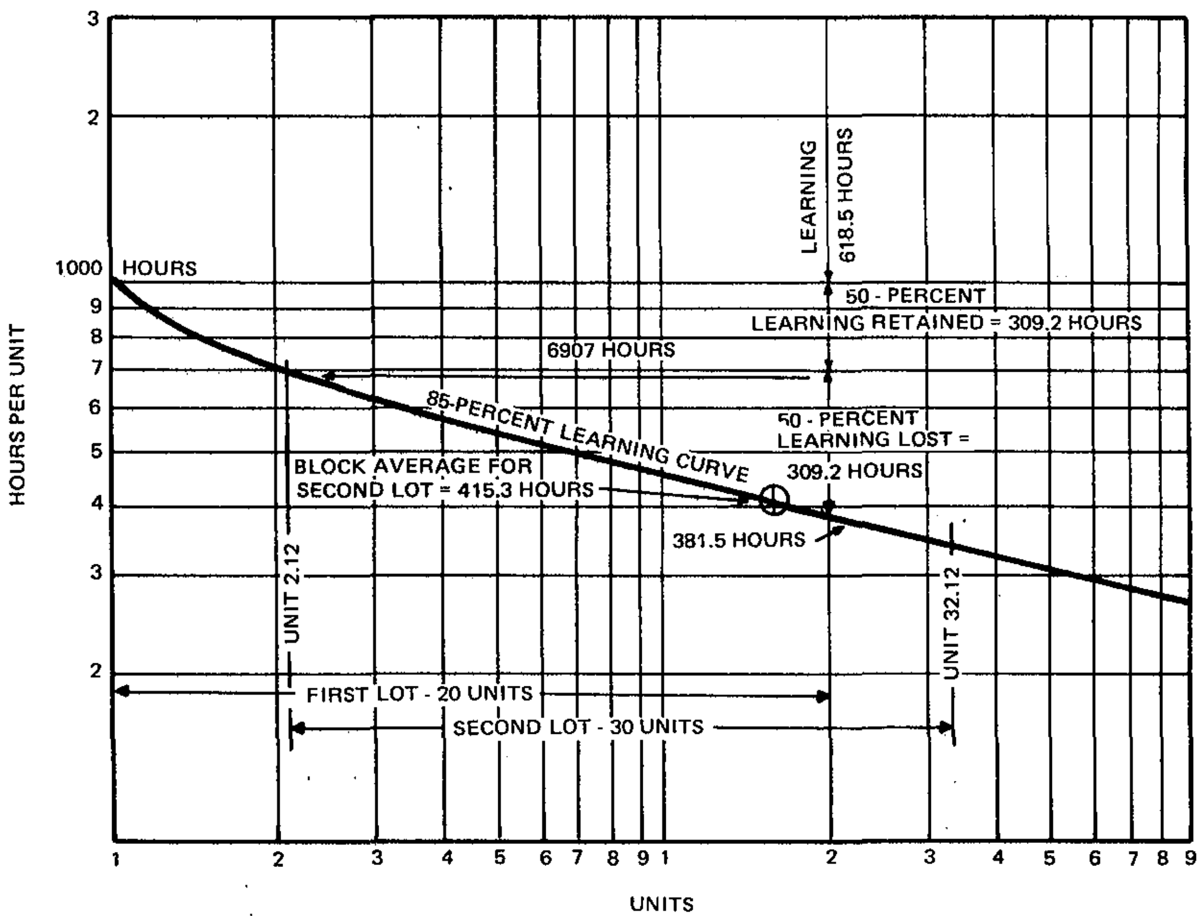

Figure A-17. Anderlohr's Hypothesis

Personnel. Only 75 percent of the trained production personnel are still available for the follow-on contract after a 6 month production break, and it is estimated that, of these retained personnel, 33 percent of their individual experience is lost. The learning retained in personnel is:

20 x 75 x 66 = 10 percent

The learning lost is:

20 - 10 = 10 percent

Supervisory. After a 6-month production break, only 75 percent of the supervisory personnel remain available, and it is estimated that 33 percent of their individual know-how has been lost. The learning retained and lost among supervisors is thus the same as for production personnel.

Continuity. The productive continuity is completely dissolved and work stations are dismantled during a 6-month production break. Thus, all of the 20 percent weight allotted to this area is lost.

Methods. Following the 6-month production break, it is estimated that 10 percent of the method sheets will be lost, destroyed, or made unuseable. The learning retained is:

20 x 90 = 18 percent

The learning lost is:

20 - 18 = 2 percent

Tooling. Subsequent to the 6-month production break, it is estimated that 60 percent of the tooling left from the previous production is available. The rest was soft tooling and is either lost, destroyed, or dismantled. Calculating as above, the learning lost is 8 percent.

The total learning loss (table A-10) is 50 percent of the learning achieved on the first lot of units. Figure A-17 shows that, for the 20th unit, the company had reduced production time by 618.5 hours. This time could be called learning hours. But it is estimated that 50 percent, or 309.2 of these learning hours, was lost as a result of the production break. This must be added to the 381.5 hours needed to produce the 20th unit. The sum, 690.7 hours, is the theoretical production time as the company is starting to produce the second lot of units.

Table A-10. Summary of Learning Loss

Factors	Assigned Weights (%)	Estimated Learning Loss (%)
Personnel	20	10
Supervisory	20	10
Continuity	20	20
Methods	20	2
Tooling	20	8
Total	100	50

The point at which the learning curve intercepts 690.7 hours is the starting point of the second lot. This gives 415.3 hours as the estimated average time needed to produce each of the 30 units. It is interesting to note that, if no consideration had been given for learning retention, the lot average would have been estimated at 450.4 hours, a difference of 1053 manufacturing hours for production of the entire lot.

The weights and estimated loss of learning assigned in the hypothetical case were described in Anderlohr's original work as an oversimplification for ease of calculation and explanation. Both the weights and estimated loss of learning should be developed on an individual basis. Anderlohr provides a matrix table A-11), including weights and related time frames, accompanied by a sample calculation, which was negotiated with a major contractor for the purpose of estimating loss of learning. It is expected that the weights and percentages will receive further refinement as actual related information become available.

SUMMARY

The material presented herein was intended to impart a basic understanding of this subject. It is recommended that significant study and effort be put forth in order to accumulate the knowledge, both in theory and technique, not covered by this discussion. The material covered in the bibliography will provide a point of departure for this in-depth study.

Probably the most significant aspect of this discussion is the word experience itself, for no matter what elements (slope, unit one, and so on of a curve are proposed, the acceptance of the data must be based on the singular criterion of the contractor's experience. Arbitrary considerations must be viewed on the same basis as any other pure estimate and are subject to adjustment during the negotiation phase of the procurement.

Table A-11. Loss of Learning Matrix

BREAK IN PRODUCTION							
			Break Time				
Loss of Learning			Days*		Months		
Weight	Element	Description	10-30	31-90	3-6	6-12	12 or more
30%	Employee Learning	Loss of Personnel	10%	20%*	40%	50%	100%
	Retained Personnel	Loss of Talent	10%	25%*	45%	70%	100%
20%	Supervisory Learning	Loss of Personnel	0%	10%*	25%	40%	65%
	Retained Personnel	Loss of Talent	5%	10%*	20%	30%	40%
20%	Continuity of Production	Work Station Layout	50%	75%*	100%	100%	100%
15%	Tooling	Hard Tooling	0%	0%	10%	20%	30%
		Soft Tooling	10%	20%	35%	50%	75%
		From Soft to Hard	50%	50%	50%	50%	50%
15%	Methods	Hard Tooling	0%	5%	10%	20%	20%
		Soft Tooling	5%	10%*	20%	25%	25%
		From Soft to Hard	50%	50%	50%	50%	50%

*Example of 30-90 days production break calculations

Employee Learning (Loss of Personnel)	Weight 30% x 20% Loss	=	6%	12%
(Retained Personnel Loss of Talent)	Retained Weight 24% x 25% Loss	=	6%	
Supervisory Learning (Loss of Personnel)	Weight 20% x 10% Loss	=	2%	3.8%
(Retained Personnel Loss of Talent)	Retained Weight 18% x 10%	=	1.8%	
Continuity of Production	Weight 20% x 75% Loss	=		15%
Tooling	Weight 15% x 20% Loss	=		3%
Methods	Weight 15% x 10% Loss	=		1.5%
Total Loss of Learning				35.3%

Appendix B. EVALUATING FABRICATION: ANOTHER POINT OF VIEW

Because most contractors divide their direct shop labor into the general categories of fabrication, assembly, and test, and because the greatest effort among these usually is fabrication, we are devoting this appendix to describing the basic ingredients involved in the process of fabrication. Moreover, many of the concepts you will find covered in this appendix apply equally as well to the assembly and test processes.

We will define fabrication as everything except assembly and testing, that physically happens to raw or semifinished material and adds to its value and brings it closer to a finished state. The following types of operations are fabrication operations:

- Machine shop operations
- Sheet-metal operations
- Electroplating and metal-treating operation
- Painting operations
- Silkscreen, etching, and engraving operations

Some types of operations, while they are actually fabrication in nature, are considered under the general category of assembly. For instance, wire preparation and weld grinding have the characteristics of fabrication operations, but because they usually are performed in the assembly areas of the plant, they fall into that category of labor.

The fabrication area of a manufacturing facility physically contains some portion of all the direct costs listed on the DD Form 633. In this respect, evaluation of fabrication costs will compel you to run the entire gamut of cost analysis procedures. On the other hand, the well-defined nature of fabrication operations is such that documented labor standards, allowance factors, and production records usually exist, thereby making evaluation of fabrication much easier than it otherwise would be. "Comparison" is the key word here, and many sources of comparative values are available.

Because fabrication generally consists of machine shop and metal-working operations, published recommendations are abundant for the variables (speeds, feeds, cycle times) that affect production times. Although two products may look and function differently, their basic units--the piece-parts--are fabricated and machined using the same methods, tools, and machines. Therefore, the same criteria for performance and the same standards to predict and judge output can be used on one as well as on the other.

The cost of fabrication is expressed in terms of the time to perform an operation--or sequence of operations--on a quantity of parts. An evaluation of fabrication costs cannot be done easily on a "macro" level. That is, learning the total time to fabricate a quantity of product will not supply you with the kind of information required to make a valid assessment. A "micro-level" evaluation calls for determining the various factors that influence fabrication costs and for evaluating these factors as to the extent of their influence. This cannot be accomplished from a distance; it will require an on-the-floor appraisal of the contractor's production environment.

The following is a brief outline of the kinds of fabrication cost (time) influences about which information should be gathered during the on-the-floor evaluation. The following influences subsequently will be discussed insofar as these factors affect unit fabrication costs.

- Machine Shop Basics
- Hard Tooling
- Soft Tooling
- Numerical Control
- Machinability

MACHINE SHOP BASICS

Because most fabrication labor is incurred in the machine shop, or "piece-part" shop, the elements of fabrication will be defined in terms of machine shop operations and procedures. With regard to practices within machine shops, variations will be found from one contractor to the other. For this reason, this discussion is introductory and is designed to acquaint you with fabrication, not to make you an expert. In addition, several good texts are available which describe in detail the intricacies of machining processes.

Although the various machines or processes have individual characteristics, the elements involved in their operation are very similar.

Also, all the operators are human beings, so they are all subject to the same allowance factors. Basically, the time it should take to perform an operation on any part on a specific machine is made up of the following components:

- The machine preparation time (setup time)

- The part run time (operation time)
  (1) Part handling time
  (2) Machine positioning and cutting time

- The machine teardown time (usually included as part of the machine preparation)

- Miscellaneous allowances.
  (1) Personal, fatigue, and delay (PF&D)
  (2) Special allowances:
    (a) Tool-sharpening and tool-changing
    (b) Dimension-checking
    (c) Housekeeping
    (d) Other

Items fabricated in the machine shop are made of any of a variety of materials--such materials as aluminum, steel, brass, plastic, rubber, and composition-type materials (teflon). For purposes of this discussion, we will assume that parts being machined are aluminum so that the presentation of examples will be consistent. Unless parts are very large, thereby affecting handling times significantly, there is no difficulty in translating between different materials. After we have reviewed machine shop basics, we will discuss this translation between materials under the topic of "machinability."

No matter what machine process is being evaluated in a typical production machine shop--as opposed to a model or prototype shop, with which we are not usually concerned in a direct cost analysis--the following set of basic ingredients will always be found:

- The machine or tool operator

- The machine itself (including miscellaneous associated equipment)

- The cutter

- The work material

- The dimensioned drawing of the finished part

- The route sheet

These items will be discussed briefly in order to clarify some basic machine shop concepts and terminology.

(1) The Operator. This man (or woman) is an hourly employee, often belonging to a union, who is sometimes paid some kind of incentive bonus for producing at or above a nominal company-determined rate of output. The important concept here is to consider all operators as *average experienced* workers, performing with *reasonable* skill and effort. The man is no superman and yet he knows his job. He has human failings and cannot be expected to work at the same efficient pace 8 hours a day, and for this reason allowance factors, such as personal and fatigure allowances, are developed. A human operator has an important virtue, however, that a machine could not claim: the ability to improve his productivity through "learning". When evaluating labor productivity, it is important to determine to what point in the learning process the operator (usually operators, as a whole) has progressed.

(2) The Machine. Machines that fabricate components required for F-Cognizance products fall basically into three groups: (1) hand-operated and hand-powered; (2) hand operated and electric motor powered, and (3) numerically controlled (NC), tape-operated, and electric-powered. With each upgrade in sophistication, the operator becomes less of a factor in the operation time but more of a factor in the setup time. In fact, some companies employ special setup men for their NC equipment preparation and low-wage personnel for the tedious operation of these automatic machines.

Actually, the extremes in machining will not usually be found in the production environments that you will encounter. Hand-manipulated machines are usually used in model shops only, and totally automatic equipment, such as the transfer machines that are used in automobile manufacturing plants, are used for the true mass production environment. That leaves the middle ground for the fabrication process you typically will encounter. The types of machines that you should become familiar with are the conventional mills, drills, lathes, punch presses, and the somewhat more sophisticated (although the machining principles are the same) numerically controlled machines.

Along with a machine comes its complement of tooling and accessories, such as rotating rables, indexing heads, vises, various clamps, wrenches, and gages. Special tooling, fixtures, jigs, and the like although not kept at the machining location, are also indispensable for efficient fabrication. In fact, it is not surprising to find that by doubling the tooling cost, total fabrication cost will be halved for a given part.

(3) The Cutter. Machining operations enhance the value of raw material by changing certain physical dimensions of the material. They do this by either bending the part into another form or by removing some of the original material. For the most part we will be interested in the material removal operations, because the forming operations are much less complicated.

In order to remove chips of metal from a work piece efficiently, the sharpened blade of a cutter must come in contact with the work piece at the proper speed and angle. Naturally, the cutter material must be harder than the work material for metal removal to be effective. In other words, cutter hardness will always be greater than material hardness.

Machining tools are not cheap, and one of the cost factors that a company tries to minimize is tooling. Another cost to be considered is the removal, sharpening, and replacement of cutters as they become dull. Dull tools, although they may still perform their material removal task, produce a poor quality of product, with rough finishes and unnecessary burrs left on the part. Labor supervision realizes this fact, and this is why a tool attention allowance (special allowance) is given to machine shop operators, unless designated indirect labor personnel perform this function.

It was mentioned that a change in work material may call for a change in cutter material. However, because cutters must be much harder than the material on which they are working, the variety of cutter materials is not as large as that of work materials. This will be discussed in greater depth under the discussion on machinability, but for now the rationale is simply this: the softer the cutter for a given work material, the slower must be the peripheral speed of the cutter passing the work, and this means a longer and costlier operation than would be the case if the cutter were sufficiently hard. Therefore, a sufficiently hard cutter should be used, although it may be more expensive than a softer one, to avoid the cost of frequent tool attention and lengthy operation cycles.

Because the cost of fabrication is a function of the time to fabricate a part, a few words should be said about how cutting tools affect the make time (setup plus run time) of a part. A high-speed tool-steel cutter may be sufficiently hard to machine aluminum, but to machine stainless steel at the *same feed and speed* as the aluminum would require a carbide-tipped cutter. But because the carbide cutter is more expensive to buy and sharpen, there is a tradeoff to make between choice of tool material and feed rate. This decision usually is made by the manufacturing engineer when he specifies the method of fabrication. To perform your analysis, you need not have his technical data or his experience, but you should be aware of the different sources of cost involved in the machining operation.

The cutting tool can also affect the time to set up the machine. There are two types of tools: common and special. Common tools, such as often-used drills bits (1/8-, 1/4-, 3/8-, and 1/2-inch in diameter), perforation tools, milling cutters (1-inch-diameter end mill), and bandsaw blades, are usually stored in the immediate vicinity of the machine and sometimes remain set up and ready to be used. Rarely used tools, such as fly-cutters and specially shaped punches and dies, are stored in the tool crib. Part of the time to prepare a machine for fabrication, and sometimes a very generous part, is allocated to securing the proper tool from the crib, locating it on the machine, and returning it to the crib at the end of the job. This cost should not be incurred for "common" tools and often presents a problem to shop supervision, because operators are prone to keeping a "crib" tool at their station in anticipation of using it soon on a subsequent job.

During your floor analysis, give some thought to how a contractor controls his tool dispersement, to whether or not and by how much labor is beating standard setup times by hoarding tools at their work stations, and to how much time is lost obtaining or waiting for tools.

(4) The Work Material. Figure B-1 gives a general picture of how different materials affect fabrication time. No consideration is given to the weight differences between the materials in this context, although, in the extreme case of very large parts, weight would be an important factor.

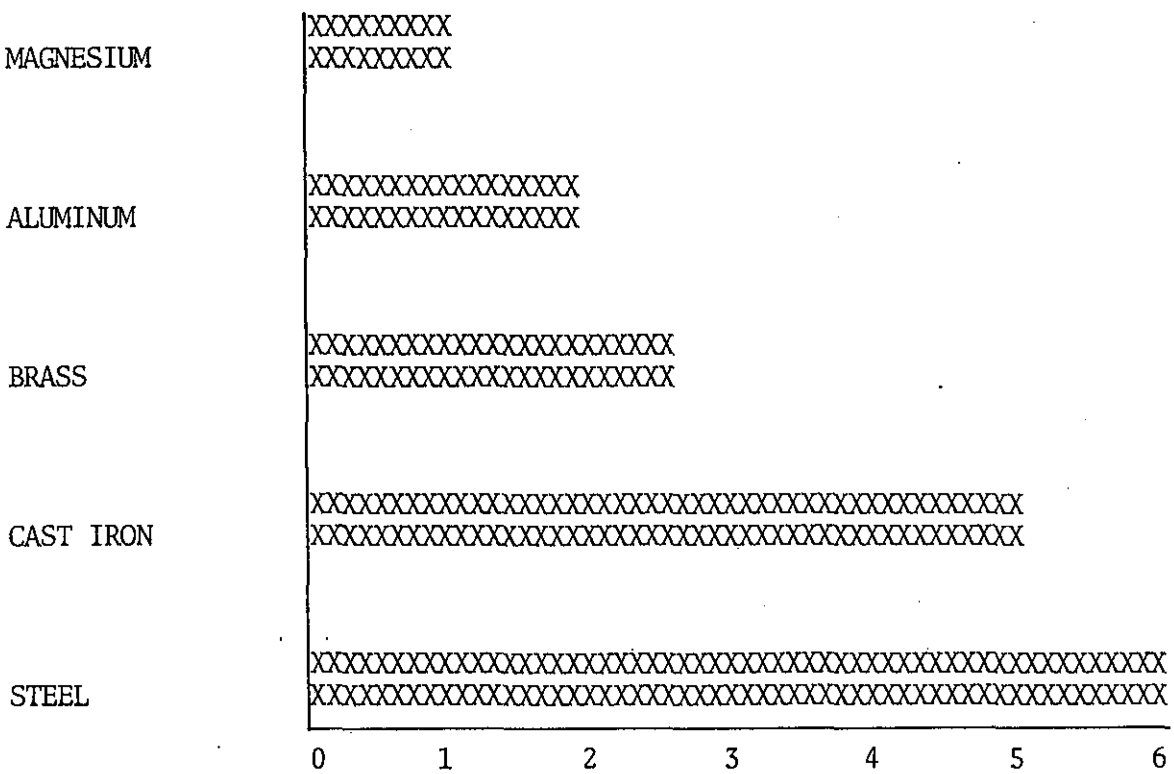

Figure B-1. Relative Machining Time

The weight effect would be significant in determining handling times. The usual method for taking weight differences into account is to assign a multiplying factor to each major class of material, with aluminum having a factor of 1.00. The factor is then multiplied by the standard handling time for aluminum. In this case, copper might have a factor of 1.50 and steel a factor of 2.00. This would indicate that, for large parts only, it takes twice as long to get, position, clamp, unclamp, and put aside a part made of steel than one made of aluminum.

The composition and characteristics of the work material also affect the method of fabrication. Parts made of magnesium often cause disgressions from standard manufacturing methods. Although magnesium offers a weight advantage for airborne or missileborne components, it suffers from a lack of maleability and ductility. For this reason, before it can be formed or bent into other shapes, it must be heated in an on-the-floor furnace to prevent cracking as its shape is changed. Extremely large or small parts present individual situations that you will have to evaluate as they arise. In the main, they will be the exception rather than the rule and a great deal of time should not be spent in analysis of seldom-occurring situations.

(5) The Drawings and Blueprints. Drawings of piece-parts to be manufactured in the machine shop are obviously essential operator tools. Information typically included on production drawings consists of some or all of the following:

(1) Part number, name

(2) Originator, date of drawing, approvals

(3) Material specifications, form, composition, applicable military specifications, scale

(4) Notes as to special considerations and revisions

(5) Tabularized key of hole patterns, special shapes and individual holes along with thread, counterbore, and countersink descriptions

(6) Detailed, dimensioned, and scaled drawings of all views of the part necessary for efficient fabrication

(7) General and individual dimension tolerances

(8) Finish and weld requirements

Drawings may originate with the contractor, if he had a development contract for such a purpose, or they may be supplied to him by the Government. In any case, production inefficiencies should not be blamed on drawings of the product; rather, the drawings should be revised to correspond to any changes that may have occurred.

(6) The Route Sheet. The industrial estimator receives a blueprint and is asked to make an estimate on the time to fabricate the part. His first step is to break down the job into the necessary operations. On a form known as a "routing sheet", or a "manufacturing outline sheet," (see figure B-2), he writes the operations in sequence and in detail. The method outlined by him represents the best manufacturing process within the limitations of the available equipment in the shop. On this outline he gives each operation a number, describes in detail what is to be done on each operation, designates the type of machine on which the operation is to be performed, and lists the tooling required.

The form in figure B-2 is known by different names in different shops--such as a "manufacturing outline sheet," a "routing sheet," and a "travel order," and a "process sheet." Its function is the same in all shops, and it usually follows the job through the shop. The standard times are inserted by the estimator after he makes his element breakdown on the various operations.

HARD TOOLING

A contractor's tooling can affect his efficiency as much as the skill of his work force. An operator can work at 120 percent efficiency during an 8-hour day, but if the amount of his work is based on inefficient tools and facilities, he might just as well have stayed home. On the other hand, all the latest equipment, sharpest cutters, and individualized tools are no excuse for a machine operator to slow his job pace. The central point to remember in appraising a contractor's tooling is whether or not his costs reflect the better of either what he has or what he should have.

In other words, if a contractor has not purchased any new machines in 30 years and all his operators are sharing wrenches and gauges, you should realize that this is inefficient and the Government is probably being asked to pay for it. Conversely, if a contractor has many of the latest equipments and all operators have a full complement of hand tools, then you should expect a reasonably high degree of productivity to be quoted by the contractor.

One purpose of a floor evaluation and appraisal is to identify areas in which changes or improvements in a contractor's methods or facilities will decrease his cost and thereby decrease the cost of the product to the Government. One of these areas is hard tooling and in particular machine tools. Once it is decided how a part is to be fabricated in a machine shop (that is, what the sequence and type of machines to be used will be) there is a lower bound on the cost of that part. The contractor may have a set of production standards that is beyond reproach, a highly skilled work force, and extremely capable manufacturing engineers. With these assets, he will quote the cost of a part, produce support data for that

ABC MACHINING COMPANY, INC.

MANUFACTURING OUTLINE					Plant	Location	Division
					S.M.	A	Tooling
Part Name Bracket-Fus. Sta. #522 lower Elev. Cable Pulley	Perm.	Temp.	Page 1 of 1	S.O. Number Std. Part	Tooling Number A65-242129-1DS		

Item	Al. Alloy Casting Operation	Oper. No.	Method	Tools	Dept.	Std. Hours Run	Std. Hours Setup
10	Flycut Attaching Surface to 1/4 dia. 1 IPM 600 RPM	62A	Miller	S65-242129-1MF1	1	.030	.4
20	(.200) Drill (3) #10 (.193) dia. holes 1800 RMP 3 IPM	31B	Dr. Press	S65-242129-1DJ1	1	.025	.3
30	Spotface 1/2" dia. 3 places 1200 RPM	31C	Drill Press		1	.012	.3
40	(.499) Mill (.505) dia. between bosses & 5/16 width of bosses to (2) places 750 RPM 16 IPM	62D	Miller	S65-242129-1MF2	1	.033	.5
50	(.259) Line drill (.252) dia. hole thru bosses 1800 RPM 3 IPM	31E	Dr. Press	S65-242129-1DJ2	1	.017	.3
60	Mach. 1-25/32 R. pulley clearance 2400 RPM 3 IPM	31F	Dr. Press	Std. Pulley Cutter	1	.033	.3
70	Burr Method 1C	01G	Bench		1	.025	--
80	Inspect Method 3AN	H	Inspect	Lor Rate = .25 Min. Lot = 40	113	--	--

Figure B-2. Typical Manufacturing Route Sheet cost, and defy you to produce it less expensively. The only flaw may lie in the fact that he is operating with 100 machine operators, all of whom are manning hand-operated drill presses and milling machines.

It is up to you to recognize that traditional fabrication methods will yield only limited productivity relative to more sophisticated methods. The contractor should be informed that wherever savings can accrue to the Government based on improved methods, these methods should be substituted for those of less efficiency. This is the reason for value engineering clauses in many contracts. The Government is not opposed to paying for a contractor's capital expenditures, as part of overhead rates, if the resulting cost reductions outweigh the initial expense.

In order to estimate savings due to equipment improvements, two sets of data are required: (1) the contractor's present method and its cost on a few selected high-cost parts, and (2) the alternatives to the contractor's method and its cost. The first set of data should be supplied by the contractor, and it should include his industrial engineering standards, process or route sheets, the part specifications, and similar items. The second set is one you will have to supply and includes such information as types of NC machine tools available, when they are advantageous, case histories of their use, and some general estimating parameters. Information regarding NC equipment and its advantages follows this discussion, but it will be up to you to identify where the need for equipment improvements is most obvious and then bring this need to the contractor's attention.

There is another side of the capital-expense-for-equipment coin. Rather than a contractor's being ignorant or reluctant to improve his facilities, he may be overzealous--he may have included as part of the cost to produce a given part the cost of a new NC machining center or even the cost of an old machining center that already has been partially paid for. Machines of this type range from \$25,000 to \$150,000 (or more depending on peripheral equipment and degree of sophistication). Your responsibility is to validate this expense as to its true worth and its method of cost allocation, if this action has not been taken previously by DCAA.

Other hard-tooling expenses, which are smaller than equipment expenditures but which are purchased as direct tooling in higher quantities, are metal cutters, drill jigs, and special fixtures. You probably will be unable to evaluate each of these individual costs in the short duration of a direct cost analysis, but nevertheless a few time-saving approaches to evaluation are open to you. Comparison of a contractor's direct material costs for tools with the tool costs on prior buys and the other contractor's tool costs is one basis for evaluation. You also can request sample cost data for some of the relatively expensive tooling. A key question here is whether it is a special one-of-a-kind tool, or whether it can be (has been) used on other contracts or on other parts of the same contract.

The cost of one-of-a-kind tools, tools that can be used only for a particular part because of dimensions, hole patterns, and so on, should be reviewed on a sampling basis. Such tools probably will be included under the category of "other costs," or possibly in the manufacturing overhead account. If they are a direct charge, they fall into part of your evaluation. Special tools are purchased usually because they provide a more efficient method of fabrication than ordinary tools. However, their high purchase or make cost cannot be justified unless a high volume of production is expected.

Your task here is to request cost information for the alternative methods of fabrication, one of which is the special tools in question, and evaluate the alternatives relative to each other. One of the pitfalls of this type of "reevaluation" (the contractor has supposedly already done it) is using preselected contractor data. You can avoid this by evaluating the special tools of *your* choice, not the contractor's, and comparing the furnished cost data for consistency.

The question of whether the special tool can be used again should be kept in mind. In some cases the answer is obvious and in others some thought might be required. For instance, a plate punch and die used to perforate 20 individual shapes in a piece of sheet metal cannot be used for any other part without considerable modification (therefore, it would be a direct charge against that part), but holding fixtures used on milling machines and drill presses are often made to be adjustable so they can accommodate parts of varying sizes. The cost of these tools should be considered as a capital investment and prorated as manufacturing overhead against all the parts for which they are used.

In addition to sampling tooling costs for accuracy and justification, the "quick look" method of overall comparison can also be used. A valuable resource in direct cost analysis is historical data accumulated not only for the contractor being evaluated but also for other contractors producing similar products. Assuming two contractors are using similar accounting techniques such that their direct tooling costs can be distinguished from other direct costs, you can use simple comparison as a guide to further analysis. This is not to say that because a cost has been incurred it is necessarily justifiable, but at least it provides a basis for comparison.

SOFT TOOLING

The paperwork used by direct personnel to fabricate a part is commonly called soft tooling. This paperwork describes what a part looks like, how it is to be routed through the shop, what tools and machines are to be used, and what inspection and test requirements are imposed.

The time required for fabrication, the amount of support engineering needed, and the extent to which engineering changes will occur all depend on product complexity. Complexity is not a characteristic that can easily be quantified; it has to do with what new functions, or new ways to perform old functions, are associated with this product. If a contractor proposes an amount of direct labor or materials to support engineering changes owing to product complexity, at some time you will have to evaluate this cost as a percentage of the total direct cost. In evaluating complexity, an excellent source of information is the contractor's drawings of assemblies and component parts. Familiarity gained through experience with the product in question and similar products will be assets, because evaluation of complexity from engineering drawings and specifications is a totally subjective process.

In the area of fabrication, complexity manifests itself in the magnitude of the dimensional tolerances called for in the product design. An examination of some representative drawings should give you an idea of the skill or craftsmanship expected of machine shop operators. When looking at a drawing, any dimensional tolerance given in fractions of an inch (±1/8, ±1/32) is not considered difficult to hold. A tolerance of ±0.020 inch is typical of conventional machine shops. Below this figure and down to a minimum of ±0.005 inch, more care and checking is required. Figure B-3 gives the general relationship between tolerance and relative cost of production, assuming traditional machining methods. As is mentioned in the discussion of NC equipment, more sophisticated methods than these have the ability to hold closer tolerances (±.0001 inch) time after time (this ability is called repeatability).

In metal-removal operations one of the key variables affecting fabrication time is the feed rate of the part traveling by the cutter. The process or route sheet, which accompanies a lot of parts as it moves through a shop in the fabrication process, usually specifies the feed rate for each machining operation. The feed rates are specified by the manufacturing engineer based on his experience and tool manufacturer recommendations. When the process sheet reaches the shop floor, the machine operator may choose to ignore the engineer's instructions or to attempt to follow them. If the specified feed rate is too slow, the operator can increase it manually and finish his work more quickly or at least with less continuous effort. A feed rate that is too fast will cause poor quality, cutter dulling, and general complaints from the operatin personnel.

One of your tasks in evaluating soft tooling is to verify that the specified and actual feed rates are not widely apart. Estimates of fabrication costs appearing in the DD Form 633 are based on the engineer's specified feed rates in conjunction with industrial engineering standard times. If operating personnel discover over time that they can increase the feeds and speeds on their machines in excess of the values listed on the process sheet, the result will be what is known as "inflated labor

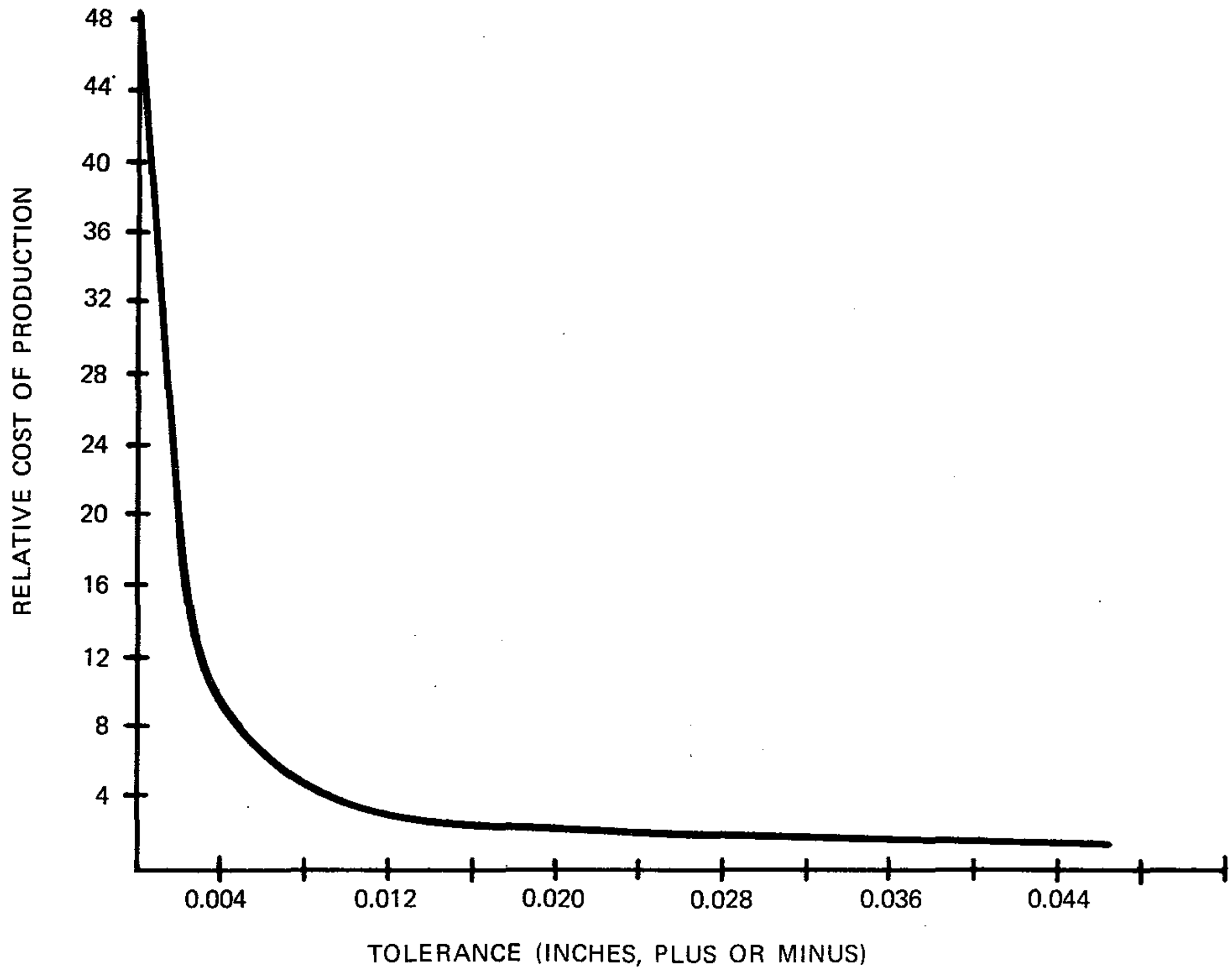

Figure B-3. The Relative Cost of Production standards." Inflation of labor standards can occur in almost any manufacturing area where these standards are quantified and methods are documented. Creeping changes in methods are then implemented by direct labor personnel, but not to the extent that they are obvious to management or to the contractor's industrial engineers. One such change is the feed rate in metal-removal operations, and it is discussed here because it is something that can be checked easily while on the production floor.

Once you gain access to the part of the contractor's soft tooling that indicates machine feeds and speeds recommended by the manufacturing engineer (namely, the process sheet for a given part), you will be ready to begin a part of the floor evaluation. You will have to know where on each of the different machines the feed control setting is located. After you learn where they are, it is just a matter of making observations of feed settings on as many machines and different parts in current production as you feel is representative of the plant conditions.

NUMERICALLY CONTROLLED MACHINE TOOLS/PROCESSES

CONDITIONS UNDER WHICH NC EQUIPMENT IS INDICATED

- At least some parts are of complex design requiring different manufacturing processes and subject to occasional design changes.

- Lot sizes vary, but are generally small (less than 500), and lead times are an important factor.

- The parts require some precision-machining to meet close tolerance requirements, high reliability, weight restrictions, or other stringent standards.

- At least some of the parts require specialized jigs, fixtures, dies, or templates for their manufacture.

- Some of the parts require prolonged processing by skilled machinists.

MANUFACTURING ADVANTAGES OF NUMERICAL CONTROL

Flexibility

- NC tape can be verified and corrected before machining first part.

- Prototypes may be made and inspected, and design changes incorporated, although the only tooling change required is the paper tape.

- The NC machine usually has manual controls that can override the tape for specific one-of-a-kind changes.

- Mirror images may be made from a single tape by manually changing the directional sense of any axis.

- Small modifications to a part can be handled without complete retooling.

Accuracy

- Tolerance accumulations owing to operator judgment, setup accuracy, tooling, and interpretation are nonexistent.

- Machine response is the only factor affecting the ability of the process to hold a tolerance.

- NC equipment have resolutions ranging from 1/32 inch down to 0.000010 inch for point-to-point and 0.002 to 0.000020 inch for contouring systems.

- NC has minimized the possibility of human error, given a proved paper tape.

Repeatability

- Repeatability is a significant advantage when making many short runs of a part.

- Both rough and finish cuts can be accomplished with one tape by using an undersized cutter for the rough cut.

- The ability to produce symmetrical cuts would be of dubious value without superior repeatability.

- Because guiding fixtures, templates, or tool-locating devices are unnecessary, the deterioration of their accuracy is not a factor.

- With precise repeatability, 100 percent inspection can be eliminated and replaced by a much cheaper reduced inspection plan.

- This incidental inspection savings often has been entirely responsible for economic justification of NC equipment.

Increased Productivity

- NC minimizes "air-cutting" time because positioning to within 1/16 inch can be done at rapid traverse rates of up to 200 inches per minute (ipm).

- Because many conventional operations can be accomplished in a single continuous cycle, the machine-controlled time is often 90 to 100 percent of the total cycle time. This allows the operator to use his time more efficiently and even to attend more than one machine at a time.

High Machine-Tool Utilization

- Blueprint and part analysis is shifted to the engineering office from the shop floor while a machine stands idle.

- Although NC sometimes requires two or three times as much setup time as required by conventional machines, NC equipment typically does the job of from six to 12 single-cutter machines.* Once it is set up, it will continue to operate providing utilization factors of more than 80 percent.

Tool Savings

- Part clamping with NC often can be done using standard "C" clamps, strap clamps, toggle clamps, or a conventional single or double vise.

- Expensive one-shot tooling can be eliminated.

- Elimination of tool storage facilities, required for conventional jigs and fixtures, are in many cases grounds for great savings.

Reduced Lead Time

- Weeks of lead time owing to hard-tooling manufacture can be condensed to a few days once the part analysis has been completed.

- Defense contractors, often confronted with numerous design changes and model buildings, find greatly reduced lead time invaluable.

Reduced Workpiece Handling

- Because many operations are performed at one NC machining center, handling at the workplace is reduced, thereby cutting costs.

- Material handling between stations is cut drastically, reducing the risk of damaging intricate and sensitive parts.

- Bottlenecks are not as great a problem as in former methods because the number of machining stations are condensed from five or 10 to one, two, or three.

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*A typical numerically controlled punch press may take up to three hours for a setup to punch twenty differently configured holes and 1.00 minutes run time to punch all twenty holes (.05 minutes per hole). The same operation on conventional punch presses would require ten hours of setup (.50 hours per setup) and 5.00 minutes run time to punch the same twenty holes (.25 minutes per hole).

Impossible Parts Made Possible

- Parts formerly fabricated from several pieces can now be cut from a solid piece.

- Parts formerly bought from outside suppliers can now be made in house, thereby increasing control of costs.

MACHINABILITY

FACTORS INFLUENCING MACHINABILITY

"Machinability" involves the economical removal of metal by a machine tool. It is expressed in terms of the cutting speed (surface feet per minute) of either the workpiece as it passes over the cutter or the cutter as it passes through the workpiece.

Our purpose in discussing machinability is to explain how to derive a good estimate for machine shop fabrication of electronic components. In addition, knowledge of machinability factors will help you produce this estimate in a minimum amount of time and with a minimum amount of data.

Some metals and their alloys are harder than others. Table B-1 shows the relative machinability of soft metals (magnesium) and hard metals (steel). Hard metals require more *time* to machine than soft ones, under a given set of conditions. How these conditions affect the *time* to remove material is the subject of this discussion.

Factors affecting the economical removal of material are many, and discussion of all of them would tend to detract from those of most importance. As mentioned earlier under "fabrication basics," those factors having the greatest influence on machinability and for which there exists straightforward, tabularized data as follows:

- Type of material being machined

- Cutting-tool material

- Nature of the cutting tool

- Feed rate

The material being machined is the prime consideration in determining the cutting speed for an operation. For this reason, most discussions of machinability begin with recommendations of cutting speeds for common metals. Table B-2 is such a list of recommended speeds. To it will be applied multiplying factors to account for differences in tool materials and their uses. The machine-tool operator has access to cutting tools of various qualities: the higher the quality of the cutting tools, the higher will be the machinability of the materials involved. Because

Table B-1. Magnesium Alloy Being Taken as 100, the Order of Some Metals' Machinability

Magnesium	100
Aluminum	55
Brass	45
Iron	30
Steel	20

Table B-2. Cutting Speeds and Turning, Boring, and Milling

Material	Speed (fpm)	Material	Speed (fpm)
Aluminum	1000	Malleable Iron	100
Bakelite	125	Masonite	1000
Beryllium Copper	50	Monel (Bar)	50
Boiler Plate	50	Monel (Cast)	35
Brass (Commercial Yellow)	250	Phenolic	1000
Brass (Naval)	125	Plastic	250
Bronze (Ordinary)	125	Rubber (Hard)	125
Bronze (Hard)	75	Steel (Casting) (115-140 Brinell)	75
Cast Iron (Soft)	125	Steel (Casting) (140-160 Brinell)	60
Cast Iron (Medium)	75	Steel (Low-Carbon, Mild)	125
Cast Iron (Hard)	50	Steel (Medium)	75
Copper	75	Steel (High-Carbon, Hard)	50
Drill rod	50	Steel (Stainless)	50
Fiber	1000		
Magnesium	2000		

the cutting speeds shown in table B-2 are based on high-speed tool steel with a factor of 1.00, multiplying factors must be used to make the table applicable to other cutting materials. Table B-3 gives these multiplying factors.

The machinability of materials also is affected by the character of the cutting tool--how it is shaped and used. The single-point tool is excellent for removing stock. Drills and reamers, on the other hand, usually operate at lower cutting speeds than single-point tools of the same quality--about one-half of their speed. A second multiplying factor must be used with table B-2 to show the influence on machinability by the nature of the cutting tool; table B-4 gives these factors.

Table B-3. Cutting-Tool Material

Quality of Tool	Multiplying Factor
Carbon Tool Steel	.50
High-Speed Tool Steel	1.00
Super-High-Speed Tool Steel (Stellite, Cobalt, etc.)	1.50
Carbide (Carboloy, Kennametal, etc.)	3.50
Aluminum Oxide (Ceramic Cutting Tools)	7.00

Table B-4. Cutting-Tool Machining Factors

Operation	Factor	Maximum Spindle Speeds
Turning	1.00	No limit
Boring	.75	No limit
Broaching	.25	
Counterboring:		
Solid Counterbores (Piloted	.50	No limit
Spot-Facer (Piloted)	.50	No limit
Inverted Spot-Facer (Piloted)	.50	No limit
Back Spot-Facer (Piloted)	.50	No limit
Center Reaming (Solid-Center Reamer)	.50	No limit
(For Internal Chamber)		
(For Countersink)		
Countersinking (Combination Drill and Countersink)	.50	No limit
Cutting off	1.00	No limit
Drilling	.50	No limit
Start Drilling	.75	No limit
Center Drilling	.75	No limit
Forming	1.00	No limit
Gear-Shaping Cutters	.75	200-450 strokes per min
Gear-Generating Tools	.75	No limit
Gear-Shaving Cutters	1.50	No limit
Hobs	.50	No limit
Hollow Milling	1.00	No limit
Knurling:		
Aluminum Magnesium Brass (500 fpm) Screw stock Steel, mild (150 fpm) Steel, medium Steel, hard (100 fpm)		

Table B-4. Cutting-Tool Machining Factors *(Continued)*

Operation	Factor	Maximum Spindle Speeds
Milling (General)	1.00	No limit
Metal-Slitting Saws	.50	No limit
Pointing and Facing Tools	1.00	No limit
Reaming:		
(Ordinary Reaming; Reaming for size)	.75	No limit
(Reaming for High Degree of Finish)	.25	No limit
Recessing Tools:		
(End Cut)	1.00	No limit
(Inside Cut)	.75	No limit
Threading (Without Lead Screw)		
Screw Steel		
Aluminum Stock Medium		
Magnesium Steel Steel		
Brass Mild Hard		
Dies		
(Self-Opening) 30 fpm 20 fpm 10 fpm	--	250
Dies (Button) 30 fpm 20 fpm 10 fpm	--	250
Taps (Solid) 30 fpm 20 fpm 10 fpm	--	250
Threading (with leadscrew)		
Dies		
(Self-Opening) 30 fmp 20 fpm 10 fpm	--	No limit
Dies (Button) 30 fpm 20 fpm 10 fpm	--	No limit
Taps (Solid) 30 fpm 20 fpm 10 fpm	--	No limit
Threading (Single-Point High-Speed steel tool)	.75	150
Thread Milling	1.50	No limit
Thread Rolling	1.00	No limit

Table B-2 is based on high-speed-steel single-point turning tools, depth of cuts of 0.125 inch, feed rates of 0.020 inch per revolution (ipr), and tool life of 2 hours. Variations to these parameters would lead to changes in the stated cutting speeds. The problem here is to determine appropriate cutting speeds, which directly affect revolutions per minute (rpm's) and feed rates, for such variations. The data contained in these tables at least can aid in producing estimates of machine times, and they will most certainly provide you with a good "feel" for the meaning of machinability.

USING MACHINABILITY FACTORS

In order to determine the actual time required for a tool to complete a machining operation, two parameters must be known: the distance to be machined (the length of the cut) and the tool's feed rate in inches per minute. The length of cut can be determined relatively easily by reference to the engineering drawing of the part to be machined. Estimates of feed rates for standard or typical conditions are not hard to find. However, if some degree of accuracy is required for nonstandard conditions (for example, many operations to be performed on the part or a few operations on many parts), quick-look tables of general data or "thin-air" estimates will not suffice.

The time to machine metal parts is directly proportional to the surface feet per minute (fpm) at which the work material moves past the cutter (or vice versa). The surface feet per minute depends on many variables, the most influential of which are (1) the work material, (2) the cutting-tool material, and (3) the nature of the tool and operation.

Comprehensive studies have been made by many groups to determine optimum speeds at which to machine most metals under the same set of circumstances. The results of one such study (they are representative) are given in table B-2. Now, knowing the recommended speed, you would need to get from that to a nominal feed rate in inches per minute so that your machine-time calculation can be made. Feed rate and cutting speed are proportional to an extent, and in symbols this is the relation:

$$\text{ipm} = (\text{ipr})\ (\text{rpm})$$

$$\text{rpm} = \frac{(12)}{(D)}\ \frac{(\text{fpm})}{(\pi)} \simeq \frac{4\ \text{fpm}}{D}$$

$$\text{fpm} = f\ (\text{work material, cutter material, operation type})$$

In words, the above is stated like this: Inches per minute are equal to inches per revolution times revolutions per minute. Revolutions per minute is approximately equal to four times the feet per minute divided by the cutter diameter. And finally, feet per minute as given in table B-2 is a function of and must be modified by two more factors--a cutting-tool factor and an operation-type factor.

Tables B-3 and B-4 contain the multiplying factors for cutting-tools and operation-types, respectively: Knowing these data and the data contained in table B-2, a good approximation to a reasonable cutting time can be made, provided the following have been ascertained:

- Type of work material (aluminum, steel, and so on)
- Type of cutter material (high-speed-steel, carbide, and so on)

- Operation type (milling, drilling, turning, and so on)
- Cutter diameter
- Length and number of cuts
- Nominal feed per revolution (ipr)

Although determination of a single cutting time seems to be quite tedious, remember that this procedure probably would be used only to check a contractor's standard machine data or to spot-check the proposed machine time for a given part. A step-by-step procedure will be outlined and then an example will be given to demonstrate the use of the procedure.

Procedure For Calculating Machine-Time

(1) Determine the following:
  (a) Work material
  (b) Cutter material
  (c) Type of operation
  (d) Cutter diameter
  (e) Characteristics of the cut, length, and so on

(2) Pick a speed corresponding to the work material from table B-2.

(3) Pick a factor corresponding to cutter material from table B-3.

(4) Pick a factor corresponding to operation type from table B-4.

(5) Multiply the above three values together to get the appropriate fpm.

(6) Calculate rpm (4 fpm/dia)

(7) Determine a recommended feed per revolution from table B-5.

(8) Multiply ipr by rpm to get ipm.

(9) Divide length of cut by ipm to get number of minutes to make cut.

Example

Operation: Mill a 2-inch groove in stainless-steel block, two rough cuts, one finish cut using 1-inch-diameter carbide-tipped end mill.

From tables: fpm = 50
Tool factor = 3.50
Operation factor = 1.00

Table B-5. Feeds for Single-Point Carbide Tools*

Materials	Feeds		
	Rough		Finish
Carbon Steels (10xx)		.015-.020	
Free-Machining (11xx)		.010-.020	
Manganese (13xx)		.015-.025	
Nickel Steels (23xx) (25xx)		.012-.022	
Nickel-Chrome (31xx) (33xx)		.010-.020	
Polybdenum (40xx) (41xx)		.010-.020	
(46xx)		.015-.030	
Chromium (50xx)		.010-.020	
(86xx)		.010-.020	
Stainless steels	.005-.015		.003-.007
Titanium		.008-.015	
Heat-Resistant Alloys		.015 minimum	
Cast Iron	.015-.025		.010-.015
Malleable Iron	.015-.020		.010-.015
Nickel Alloys (Monel, K-Monel) . . .	.010-.020		.003-.010
Copper Alloys:			
Free-Cutting	.007-.020		.005-.009
Average Machinability	.007-.018		.003-.008
Difficult to Machine	.003-.015		.003-.005
Aluminum Alloys	.007-.012		.003-.008
Magnesium Alloys	.010-.040		.005-.010
Plastics		.003-.008	

*Compiled from *Speeds and Freeds for Better Turning Results*, The Monarch Tool Co., 1954.

Modified fpm = 175
rpm = (4) (175)/1.00 = 700

Rec. ipr = .010 rough, .005 finish

First cut ipm = (700) (.010) = 7.0

Second cut ipm = (700) (.010) = 7.0

Third cut ipm = (700) (.005) = 3.5

$$\text{Machine Time Total} = \frac{2.0}{7.0} + \frac{2.0}{7.0} + \frac{2.0}{3.5} = \frac{8}{7} \text{ min} = 1.14 \text{ min}$$

(The time to make the three cuts is by no means the total operation time. Other elements must be considered, such as part handling time, tool positioning times, and allowances. But because machinability does not influence these other elements, they are not discussed in this context.)

EVALUATING THE CONTRACTOR'S ECONOMIC AWARENESS

By "evaluating the contractor's economic awareness" we mean determining if the contractor uses his own resources wisely. If a contractor spends more money than he should (we presume because of his economic unawareness), the Government likely will pay for overspending. Now we are concerned with finding evidence that the contractor makes wise use of his resources in the purchase and use of materials.

Remember from section II that a production lot is a specific number of parts fabricated in one production run by the contractor; a purchase lot is a specific number of raw materials or parts bought at one time by the contractor. You can evaluate the contractor's economic awareness by seeing if he has determined the most economical size for these production and purchase lots.

On one hand you know that buying in large quantities increases the likelihood of price breaks and that even for parts a contractor produces for himself he must purchase raw materials from outside suppliers. Clerical work needed for each buy is not free. And you know that some parts are lost each time a machine is set up for a new operation because the machine must be adjusted by preproduction "trial runs" until it can perform in a required way. So it seems that thriftiness increases with lot size.

But on the other hand, as we have mentioned, you must realize that keeping the materials in storage can be expensive. So, just what is a economical lot size?

An economical lot size usually lies somewhere between an extremely small and an extremely large lot. The following formulas, although less sophisticated and precise than some, can enable you to estimate just where between the extremes a particular lot size should lie. The variables you use can be estimates because the economical lot sizes themselves, at best, can represent only estimates.

EVALUATING PRODUCTION LOT SIZES

Economical production lot size = $L = \sqrt{\frac{2NUS}{IC+2A}}$,

when:

N = number of days worked per year
U = daily usage of the part
I = contractor's expected return on his investment

C = total unit cost of the part including material, labor, and overhead
A = unit storage cost per year
S = setup cost per lot

An example of how to use this formula can be devised by substituting constant values for some of the variables. Assume, then, that:

N = 250 days
I = 15% or .15

$$A = \frac{IC}{2} = \frac{.15C}{2} = .075C$$

$$U = \frac{\text{total production requirement}}{\text{No. working days to due date}}$$

With these substitutions, your formula for determining an economical production quantity is:

$$L = \sqrt{\frac{(2)(250)(U)(S)}{(.15C)+(2)(.075C)}} = \sqrt{\frac{(500)(U)(S)}{(.45)(C)}}$$

Now you can determine an economical production lot size if you can find out from the contractor the values in the formula that are not constant. The contractor should be willing to tell you his estimates of the setup and unit costs, and you can find the total end-product quantity requirements and the due date by referring to the master bill of materials or by asking the contractor's scheduling department.

Suppose you discover the following:

S = \$10 per hr X 4 hrs = \$40 (includes overhead)
C = \$30
Contract requirement for the part = 400
Contract due date = 1 July 1973
Today's date = 1 January 1972
Days remaining until due date = 378 working days

$$U = \frac{\text{contract requirement for part}}{\text{days remaining until due date}} = \frac{400}{378} = 1.06$$

You can now determine a specific economical production lot size by completing our formula as follows:

$$L = \sqrt{\frac{(500)(U)(S)}{(.45)(C)}} = \sqrt{\frac{(500)(1.06)(\$40)}{(.45)(\$30)}} = \frac{21200}{13.5}$$

$$= \sqrt{1570} = 40 \text{ units per lot}$$

Our formula indicates that the contractor's production operations would be most economical if ten lots of 40 units each were produced over the contract's 18 months.

The economical production lot size you find by this formula may conflict with the delivery requirements set by the Government. If it does, and the schedules cannot be adjusted, the contractor will have to abide by the delivery requirements. Even so, use of this formula and comparing your lot-size findings with the contractor's proposed or actual lot sizes, taking into account delivery requirements, will allow you to judge the contractor's economic awareness.

We have not intended to imply in our discussion of production lot sizes that production in the contractor's plant is not continuous, that his plant operations halt at the completion of each production run; such usually is not the case. The point of this discussion is that, insofar as possible, the contractor should produce over a specific amount of time only as many units of a particular part as he can store and handle economically.

EVALUATING PURCHASE LOT SIZES

An economical purchase lot size (sometimes called an economical order quantity) can be determined as follows:

$$\text{Economical purchase lot size} = Q = \sqrt{\frac{2UB}{IC+A}},$$

when:

U = number of units required for 1 year
P = cost of placing an order for the material (clerical hours plus overhead)
I = contractor's expected return on investment
C = unit price of the material
A = storage costs

An example of how to use this formula can be devised by substituting constant values for some of the variables. Assume, then that:

$I = 10\%$
$A = IC = 10\%(C) = .10C$
Therefore, $Q = \sqrt{\frac{UP}{.10C}} = \sqrt{\frac{10UP}{C}}$

Now you can determine an economical purchase lot size if you can find out the cost of placing an order, the contract requirements for the material in terms of units per year, and the unit price of the material. The contractor should be able to give you an estimated cost of placing an order, but if he cannot, he should be able to tell you the number of purchase orders that were generated by his purchasing department. The cost of placing an order can then be determined by dividing the number of purchase orders into the yearly budget of the purchasing department.

The contract quantity requirement for the forthcoming year can be obtained from the proposal itself or from the master production schedule, and the material unit price can be obtained from vendor quotes or from historical data recorded for similar contracts.

The application of the economical purchase lot formula can be shown if we assume that the item to be produced is an aluminum casting and that:

U = 500
P = $50
I = 10% or .10
C = $30
A = IC = (.10)($30) = #3

Then by completing our formula we find that:

$$Q = \sqrt{\frac{2UP}{IC+A}} = \sqrt{\frac{(2)(500)(50)}{(.10)(30)+3}} = \sqrt{\frac{5000}{6}} = \sqrt{8333} = 91.285 \text{ units per order}$$

Our formula indicates that the contractor's purchases would be most economical if he planned his orders so that 5 lots of 100 units would be taken into the plant over the next year of the contract. This does not necessarily mean that the contractor should make five trips to an outside vendor and buy 100 units each time. If the vendor offers price breaks for bulk buys, the contractor probably should buy all 500 units at once. But even so, the contractor *probably* should arrange for the vendor to make five deliveries, each of 100 units, over the next year.

There may be a problem here. Making deliveries to the contractor means packing and shipping expenses to the vendor, and this means that the vendor probably will raise his charges to the contractor according to the delivery requirements. The contractor, then should compare his storage costs with the extra delivery charges to see if he should have his material delivered in accordance with the original "economical purchase lot."

All of this means that our formula can tell you approximately how many purchased units a contractor should take into his plant over a specified time period considering the storage costs involved. Beyond this, you should see whether or not the contractor has shown economic awareness about price breaks, vendor delivery charges, and any other influences on material purchases.

Probably during your material evaluation the contractor will not have begun producing and buying materials for the contract under study. This means that your application of our purchase and production lot formulas likely will be on past-performance data kept by the contractor, and there is a chance that the contractor's material practices have changed since those data were recorded (if you suspect they have, you should ask the contractor about them).

We do not claim exactness for either of our formulas. But they do provide ways to check quickly for evidence of contractor economic awareness, and unless your findings are negative, you can turn your evaluation from the contractor's purchase and production practices to other influences on total direct material cost. If your findings are negative, you should recommend that the contractor change his production and purchase practices as necessary to prevent the Government from incurring extra costs due to inefficiency.

Appendix C. SYSTEMS FOR ACCUMULATING COST DATA

When costs are estimated under noncompetitive conditions--which occur for most defense contracts--a close look at how a contractor accumulates his cost data is an important part of your evaluation of his cost estimates. Under competitive conditions, your judgment about the fairness of a contractor's cost estimates can be based largely on comparisons of them with estimates developed by other contractors. Without the ability to compare cost estimates of competing contractors, each of whom is vying for a contract award, an examination of a contractor's cost-accounting system, as well as his cost-estimating techniques, becomes necessary.

The contractor's decision on which estimating technique to use is influenced greatly by the data available to the contractor. The contractor's method for accumulating data--his cost-accounting system--determines the data that will be available for him to use in his cost estimates.

COST ACCOUNTING

UNIFORMITY IN COST-ACCOUNTING SYSTEMS

In the field of cost accounting and cost analysis there are pressures for uniformity and comparability, but most of these arise from special circumstances and they are of less force than appear in the area of financial accounting. This is understandable, since cost accounting is a matter of managerial (internal) information for the most part; but any decision as to price or output policy brings cost data into close relation with the market situation. When prices are established under something less than fully competitive conditions and the restraints of the market operate imperfectly--as in the case of most government contracts--cost data must play a large role in contract negotiation and settlement. Under such conditions, the method of cost accounting can make a substantial difference in results, and variations in cost assignment may become a matter for concern. In such situations, the only way to achieve equitable settlements is to base them as much as possible on logical, consistent and valid cost measurements.

Every firm has its own characteristics and individuality; these arise from sources that may even be somewhat beyond the control of owners or managers, in adapting to the environment as to markets, products, supply of resources, choices of method and other factors. Various combinations of many factors tend to make each business different from any of the others. But further, the operation of systems to collect and process data about operations is a part of the task of management, and the outputs of such systems are generally regarded as confidential and special adaptations of managerial needs and skills.

STANDARDS IN ACCOUNTING

The idea of standards is used to a considerable extent in all business and accounting data. For instance, those actual steps taken to establish the dollar amount of an inventory are not really so important as whether the final results is acceptable. It does not matter much whether the items are counted in a particular order, or whether the count is by units, tens or dozens; the result should be precise. It is not acceptable to guess at the number of items, if an actual count is at all possible. Even when estimates are unavoidable, they should be carefully made, and checked.

To bring this to the level of cost analysis, it is clear that cost data are nearly always used by people who did not put them together. If cost figures are to be used with confidence, they must meet standards as to their content--there must be a way to be sure of what the figures mean. Direct costs should be discernible from indirect costs, not by how computations are made, or by convenience in making such computations, but by some sharply specified idea of what makes them different. The standard to be met by a "direct-cost" classification should be as nearly unequivocal as possible, because those who use the figures must know what criteria were used to separate direct costs from non-direct ones. Unless these criteria are known, one cannot understand the result. Costs that are averaged together must be reasonably homogeneous if the average is to be meaningful; bases for cost assignment must be selected in some way that is not merely arbitrary or capricious. When there are various methods available which produce significantly different results, there should be some recognized norm; and any departure from that norm ought to be explained. Better still, when there are departures from standard or accepted methods, data should be made available in such form and detail as to permit adjustment to make comparisons possible.

Until recently the technical evaluator and other cognizant government agencies have been plagued by the task of "deciphering" the intricacies within the multitude of variations of cost accounting systems. But on 4 May 1972 Defense Procurement Circular Number 99, "Cost Accounting Standards," was published and with it a major step was taken toward uniformity in cost reporting. Certain contractors as specified in the above publication will be required to submit Form CASB-DS-1, Cost Accounting Standards Board Disclosure Statement. A copy of the index page of this statement is enclosed as figure C-1.

COST ACCOUNTING STANDARDS BOARD DISCLOSURE STATEMENT REQUIRED BY PUBLIC LAW 91-379	INDEX

Figure C-1. Index Page of "Cost Accounting Standards Board Disclosure Statement"

It is suggested that you become familiar with the contents of this circular since the information provided in the disclosure statement can be of significant assistance in your work.

COST OBJECTIVES

Costs are always costs of something; that item or condition to which cost is related is a cost objective. Some of the kinds of cost objectives are the cost of products; activities; methods; functions; proposals; processes, departmental, territorial, or commodity units of organization; and channels of distribution and classes of customers. What it costs to produce an item of product, to train an employee, to speed up a process, to carry an additional amount of inventory, or to substitute one procedure for another in any of a wide variety of situations are some common examples of defining the cost objective. Any of the things or conditions which is the object of the preposition "of" in the phrase, "the cost of---"

is a cost objective. Specifying the cost objective sets the focus of interest in cost determination; it is therefore a decisive factor in the collection and assignment of costs. It is important that the cost objective be specified carefully and unequivocally; many real difficulties in cost determination arise because the cost objective has not been clearly defined.

Establishing the cost of something implies that there is some way to determine what costs are pertinent to that cost objective, properly applicable to the case at hand.

In cases where the cost objective is a specified commodity or service, it is assumed that all the costs incurred (that is, all outlays that can be related to the cost objective) should be recovered. Cost reimbursement or recovery has been qualified by the idea that such costs should be "reasonable"--not overly wasteful or inefficient. But this does not alter the need for, nor the methods of, properly identified and substantiated cost assignment.

COST CENTERS

Many contractors segregate direct from indirect costs by breaking their costs down according to cost centers. A cost center, burden center, or cost pool is an area in the contractor's facility in which a single, distinguishable type of operation, function, or activity is performed. Cost centers can be classified as productive, service, or nominal cost centers. Productive cost centers sometimes are called direct cost centers; service cost centers and nominal cost centers sometimes are called indirect cost centers.

Productive Cost Centers

Productive cost centers are units, functions, or areas where a particular type of work is done. These centers may encompass a single machine or a group of machines that are alike, and a single worker or a group of workers engaged in the same type of work.

Service Cost Centers

Individual activities that support the productive activities but do not contribute directly to the manufacture of a product (that is, they are not obviously traceable) are service cost centers. Service costs usually are classified as indirect costs; they include costs for building, machinery, equipment, tool, and power plant maintenance.

Nominal Cost Centers

Nominal cost centers exist in name only because no particular activity is performed. Such overhead costs as payroll taxes, local taxes, county taxes, and state taxes, should management desire a convenient grouping of costs, can be accumulated by nominal cost centers.

COST-ACCOUNTING SYSTEMS

The two basic cost-accounting systems are the job order cost system and the process cost system. Each of these two basic systems can be classified as either a historical cost system or a predetermined cost system, which makes possible four "pure" types of cost systems: (1) the historical job order cost system, (2) the predetermined job order cost system, (3) the historical process cost system, and (4) the predetermined process cost system. Most contractors, however, accumulate both historical data and predetermined data for use in predetermining contract costs, and many contractors apply their own variations to the job order cost system and the process cost system.

JOB ORDER COST SYSTEMS

Contractors use job order cost systems when they must estimate the end-product cost of each contract apart from the end-product costs of other contracts. That is, when each contract (or job order) has unique characteristics that preclude its end-product cost's being averaged with the end-product costs of other contracts, the contractor probably will use a job order cost system (see table C-1).

Table C-1. Job Order Cost System Compared with Process Cost System

Cost System	Production	Costs
Job Order	1. By specific job, lots, or orders	1. Accumulated by jobs, lots, or orders
	2. Specifications unique for each order	2. Calculated when job is finished
Process	1. Continuous or mass production of a single product or homogeneous products	1. Accumulated by units of product within each process or department
	2. Specifications not unique for one order	2. Calculated at end of cost period

When contractors accumulate cost data by a job order cost system, usually the contracts they handle do not require the continuous production of many units of a single end-product type. A contractor, for example, may handle special orders by which unique end-product design characteristics are specified by his customer; or he may produce some components continuously in his shop, but these components will be combined with other assembly components in some particular way specified by his customer (in these situations a combination of job order and process cost systems may exist).

Under the job order cost system, direct and overhead cost data are accumulated by each contract or order worked on by the contractor. The contractor's direct laborers identify on their time cards the jobs on which they work, and a calculated overhead rate is applied to the direct labor time recorded for each job order. The direct material requirements for each job order can be identified by bills of materials and charged to the particular job order. This method of data accumulation does not preclude the completion of DD Form 633 in the prescribed manner since gross overhead rates may also be calculated.

The difference between a regular "job order cost system" and a "job lot cost system" is that under a job order cost system, a single unit of product, such as a yacht or a house, constitutes a complete job, and under a job lot cost system, multiple units of product, such as books or toys, constitute a job lot. Heavy-machinery production, printing, shipbuilding, construction, machine shops, and furniture building are among the industries that use job order cost systems.

PROCESS COST SYSTEMS

A process cost system is used when identifying each individual end-product cost is impractical. Under a process cost system, total costs for producing a kind of unit and the number of that kind of unit produced are determined for regular accounting periods, and an average unit cost for the period is determined. Under a job order cost system, unit costs are not available until the job is completed; in process costing, average unit costs are determined at the close of cost periods and are available although a "lot" required by a contract may not even be completed (see table C-1).

A process cost system likely will be used when any of the following occurs:

- Plant production is of a single product.

- Although several products are produced in the plant, management divides the plant into cost centers, each of which is responsible for manufacturing a single product.

- The plant has been divided into separate operation or production centers, each performing specific standard operations.

- Production of a single product is for a specific period of time and is followed by production of other products for specified times with each production distinguishable by individual production data and costs.

- The relative importance of multiple products can be determined by computing weighted averages (quantity and cost) without significant distortion.

Process cost systems are used by such industries as the chemical, petroleum, textile, steel, rubber, cement, flour, sugar, and coal industries; by firms that make such articles as rivets, screws, bolts, and small electrical parts; by assembly-type industries that manufacture such items as household appliances, typewriters, automobiles, and airplanes; and by such service industries as gas, water, electric power, and heat companies.

Sequential process costing is applied when products go through a series of processes in a specified order. Costs are transferred from one process account to another as the product is transferred fron one process center to another, and the cost of the finished product is recorded in the last process center.

When a basic material goes through two or more processes, resulting in two or more end products, parallel process costing may be used. The petroleum industry provides an example of simulataneous parallel processing by which a basic material (crude oil) is processed into different end products (such as kerosene, gasoline, and lubricants) by being channeled simultaneously through different processes. In food-processing plants, several different end products may be produced in consecutive steps on several different lines, which is nonsimultaneous parallel processing.

In process costing, direct and indirect labor and material costs are accumulated according to process or department. Although distinguishing direct costs and indirect costs is usually unnecessary in process costing, evaluating the cost of a process is helped by the distinction.

In job order costing, manufacturing overhead is commonly distributed to the product usually on the basis of its ratio to direct costs, but in process costing the common denominator usually is units produced.

When more than one process is required for the manufacture of an end product, manufacturing overhead must be distributed to each process or department. When several products are produced simultaneously or in successive runs, manufacturing overhead may be apportioned within each process to products produced. To minimize the effect of seasonal production fluctuations, manufacturing overhead can be determined as a yearly cost factor and an average manufacturing overhead charge per unit can be developed. In addition, a manufacturing overhead rate per direct labor cost may also be developed (which accommodates DD From 633 requirements).

Some contractors segregate costs in order to identify certain overhead costs (material and direct engineering) apart from those applicable to direct manufacturing labor. General and administrative (G&A) costs may be identified and distributed in a manner similar to overhead costs.

Variations to, and combinations of, the two basic systems exist. For example, to have fabrication departments or processes in which costs are based on process costing and to have assembly departments in which costs are based on job order costing is sometimes practical.

HISTORICAL COST SYSTEMS

When actual cost data are accumulated after operations have taken place, the cost-accounting system is a historical cost system. Either the job order cost system or the process cost system can be classified as a historical cost system if the only data about an end product's production are accumulated *after* the end product is produced.

Historical cost data relate to:

- The acquisition, storage, and use of raw materials, parts, and supplies (these data include purchase requisitions, purchase orders, receiving reports, and summary of materials used)

- The employment and performance of labor (these data include time cards, payroll journals, employees' payroll records, and employee and department performance reports)

- The incurrence and allocation of manufacturing overhead (these data include invoice vouchers, journal vouchers, and material requisitions)

To prevent distorted projections from historical data, the following should be analyzed:

- Changes in plant layout and equipment

- Changes in products made, materials used, and methods of manufacture

- Changes in organization, personnel, working hours, conditions, and efficiency

- Changes in costs

- Changes in managerial policy
- Lag between incurrence of costs and reporting of production
- Random influences such as strikes and weather

Historical data are used in all cost-accounting systems, at least as a base for comparing actual results with predicted results. The proper accumulation and application of historical data, therefore, are indispensable ingredients in any reliable cost estimate.

PREDETERMINED COST SYSTEMS

Predetermined cost systems are cost-accounting systems in which data about the production of an end product are accumulated *before* the end product is produced. A contractor using a predetermined cost system gathers information about a job he soon will do, and with certain cost-estimating techniques, like the ones we have discussed, he can predict his costs for doing that job.

When contractors use predetermined cost data, normally these data must be substantiated by past actual performances. That is, although a contractor may use a "predetermined cost system," probably he will maintain historical records of the actual results of his past contract performances, and these historical cost data are used as a basis or as a backup for the contractor's predetermined cost data. And when he finishes work on a contract for which a predetermined cost system was used, the contractor can compare the actual results that occur with the predicted results based on predetermined cost data.

Two types of predetermined cost systems are the estimated cost system and the standard cost system.

Estimating Cost Systems

A contractor who uses an estimated cost system accumulates cost data on a "cost-estimate sheet." On this cost-estimate sheet, he jots down his guess of the direct labor, direct material, and overhead costs for producing an end product. Usually his "guess" is an estimate based on his past production of the same, or a highly similar, end product. And when he actually produces the end product for which he has estimated costs, he can compare the results that occur with his predicted results and use this experience to make future cost estimates.

An estimated cost system is one that has been developed primarily to expedite costing; it is particularly useful in such industries as the shoe, road, bridge, housing, bottling, and clothing industries, in which design is important and selling price must be quoted prior to actual manufacturing.

An estimated cost system provides management with:

- A unit cost estimated in advance that permits periodic comparison and revision if desirable

- A cost of sales figure without the use of expensive inventory procedures

- Overall economy in cost estimates

Costs determined by use of an estimating system are *seldom very accurate*.

Estimating End-Product Costs via Cost-Estimating Relationships. The cost-estimating-relationship (CER) technique allows a contractor to estimate the cost for an end product without using labor standards for the operations needed to produce the product and without calculating his net material costs. The cost for producing the end product is estimated by giving a cost value to some physical or performance characteristic of the end product. For example, if a contractor charges $10 a pound to produce one product, he may assume the cost of a similar 10-pound end product to be $100. Or if a contractor charges $100 to produce a 10-horsepower motor, he may charge $1000 for a similar-type motor with 100 horsepower.

CER's are developed by accumulating actual costs incurred in the past by the contractor for producing some type of end product. These actual costs then are related to some physical or performance characteristic of the end product, such as cost per pound or per horsepower. Then finally, statistical procedures are devised to evaluate these cost relationships.

When a contractor develops a CER, he must decide what characteristic to use as a cost basis and whether the cost value he chooses represents direct labor only or direct labor costs plus such other costs as manufacturing overhead. He also must account for any changes in his ability to produce the product and any inflation of labor and material costs, and he must allow for any cost reductions resulting from improvements in performance as experience is gained.

Finally, the contractor must develop some means to determine if his CER's are statistically reliable. There are no certain methods for determining the statistical reliability of a CER, but the reliability of a CER somehow should be tested. Unfortunately, the only real test of a CER is in the contract's final results. Are the actual costs that occur the same as the costs predicted by the CER's?

The advantages of using CER's are:

- Rapid cost estimation is possible after the CER's are developed (the actual development of the CER itself is a lengthy process).

- The effort required for estimating with CER's is small compared with the effort needed for other cost-estimating techniques.

- The procedures for developing and using CER's are more objective than are the other techniques, which depend largely on personal judgment about what may occur in the future.

- The procedures for using CER's are systematic and provide consistent estimates for easy evaluation by other persons.

- The systematic use of historical actual data is more accurate than are other techniques for estimating costs of new systems.

Some disadvantages of CER's are:

- Past practices and occurrences used for the historical cost data will be reflected in the derived equations and, therefore, in projected costs. To the extent that future practices will differ, estimation errors are likely to occur.

- Because CER's must be restricted to a few explanatory variables, they tend to oversimplify the many factors that affect cost.

- The statistical probability statements of a CER are not always clear or accurate.

- Because some programs' characteristics are outside the range of the sample data used to derive the CER, you must answer whether the trends found in the sample data will hold beyond the range of those data.

Standard Cost Systems

Standard performance, as we implied in our discussions on labor standards, is the level of performance that a contractor should be able to maintain under normal conditions. Standard costs is the cost that should be attainable for some operation or process performed under normal conditions. Standard cost data, therefore, are the data collected by a contractor prior to his production of some end product to determine what the cost of the end product should be.

"Current standards" reflect what performance should be during a certain period of time. Current standard costs are computed estimates of what costs should be in an ensuing accounting period, and they are revised from accounting period to accounting period to reflect price trends.

"Ideal standards" are based on the most favorable labor and material prices; once set, they are rarely changed. "Normal standards" are based on average prices over an entire business cycle; they are not revised until the cycle is complete.

"Basic standards" do not change after their establishment, unless physical changes to the operations themselves create the need for revised standards. The price level assumed when basic standard costs are set usually is the average price level expected for the first year following establishment of the standard costs. Basic standards are not changed in response to later price changes, and thus they represent a fixed base with which current standards can be compared.

Standard cost data are carefully computed data used to estimate future costs. But because they are developed prior to actual production, standard cost data usually are considered "should-cost" and their true validity can be determined only by comparison with results that actually occur.

COST-ACCOUNTING SYSTEMS--SUMMARY

In our discussions, we introduced you to two basic systems for accumulating cost data to be used in estimating costs; these systems are the job order cost system and the process cost system. Each of these two basic systems can be categorized further as either a historical cost system or a predetermined cost system. Under a historical cost system, the data accumulated are historical--that is, they are accumulated subsequent to the actual production of the end product; under a predetermined cost system, the data accumulated are predetermined--that is, they are developed for forecasting costs prior to the actual production of the end product.

Most contractors use some variation of these cost-accounting systems. Historical data are used in most, if not all, systems, at least for comparing predicted costs with the costs that actually occur. Many contractors combine the use of job order costing and process costing.

In this subsection, we have tried to acquaint you with how contractors generally accumulate cost data because how they estimate costs is largely based on the data available to them. And if a contractor uses a cost-accounting system that is not compatible with his manufacturing procedures, he probably will use a cost-estimating technique for which he has insufficient data to derive a reasonable cost estimate.

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