IDA

INSTITUTE FOR DEFENSE ANALYSES

# Cost Effects of a Change in Production Rate

J. Richard Nelson, Project Leader
Stephen J. Balut



Suitable for public release;
distribution unlimited.

October 1996

IDA Document D-1926

Log: H 96-003512

This work was conducted under IDA's independent research program. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

# PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) under the China Cooperative Commercial Aircraft Project, part of IDA's independent research program. It is an annotated version of a briefing presented to representatives of the China Institute of Aeronautic Systems Engineering with the purpose of sharing IDA's knowledge and experience in cost estimating and analysis.

Most of the material in this document was derived from previous work documented in IDA Document D-764, "Trends in a Sample of Defense Aircraft Contractors' Costs," [1], and in a presentation made at the 1995 Institute for Operations Research and Management Science (INFORMS) National Meeting, "Defense Contractor Overhead Costs and Trends" [2], both of which have been cleared for open publication. Because this document is a review of that previous work rather than new analysis, it has not been reviewed for technical content.

# CONTENTS

# INTRODUCTION

# Cost Effects of a Change in Production Rate

A lecture given to the

**China Institute of Aeronautic Systems Engineering**

by

**Dr. Stephen J. Balut**

**Institute for Defense Analyses (IDA)**

on

**October 7, 1996**

President Zhao Binsheng and members of the Staff of the China Institute of Aeronautic Systems Engineering, I'm proud and honored to be here speaking to you. Our visit has two purposes. First, we want to continue to strengthen our relationship with the China Institute of Aeronautic Systems Engineering by providing you with our estimate of the cost to produce an 100-passenger aircraft. That is the subject of today's afternoon session. Second, we hope to share with you some of our knowledge and experience in cost analysis. That is the subject of this lecture.

Some of you may not be familiar with the company we work for, the Institute for Defense Analyses, or IDA, as we call it. I will begin this talk by describing, briefly, the different types of work that IDA does. Following that, I will restrict my remarks to only one of those activities—cost estimating and analysis.

IDA

**Stronger defense through better decisions**

**More informed decisions through visibility to costs**

IDA is a research and development center whose primary mission is to assist the United States Department of Defense in addressing important national security issues, particularly those requiring scientific and technical expertise.

Simply stated, IDA provides the Department of Defense with information that improves decision making. One part of that information is the likely costs of future systems, such as aircraft, missiles, and ships. We know that defense decisions are better informed when the full costs of alternatives are visible and understood. But cost is not the only type of information IDA provides to the Department of Defense.

## IDA RESEARCH AREAS

- **Systems Evaluations**
- **Technology Assessments**
- **Force and Strategy Assessments**
- **High-Performance Computing and Communications**
- **Resource and Support Analyses**

This slide lists the areas in which IDA maintains expertise in order to provide advice to the Department of Defense.

*Systems Evaluations*

IDA maintains expertise in all military systems, including strategic; tactical; mobility; command, control, and communications; intelligence and surveillance; and information and computing systems. IDA systems evaluations cover all stages of development and deployment, including test and evaluation. Issues of technological risk and cost are also addressed.

*Technology Assessments*

IDA provides scientific, technical, and analytical support related to identifying, developing, and using advanced technologies for defense systems. This work involves assessments of feasibility, performance, producibility, demonstration, and development risk.

*Force and Strategy Assessments*

IDA conducts assessments relating to systems, operational performance, force structure, and national security strategy. Studies examine past and present conflicts, such as those in the Middle East and Bosnia, as well as joint exercises and peacetime operations. IDA also examines broad national security strategy issues such as proliferation, use and control of weapons of mass destruction, regional security, and arms control.

*High-Performance Computing and Communications*

IDA is a key component of the National Security Agency's research endeavor. We provide cutting-edge research in disciplines fundamental to the NSA's mission, particularly mathematics and computer science.

*Resource and Support Analyses*

IDA develops and improves methods for estimating the costs to develop, procure, test, operate, and support defense forces and systems. The people from IDA visiting here today work mostly in this area.

## COST ANALYSIS

- **The process of estimating the individual and comparative costs of alternative ways of accomplishing an objective**
- **The goal is not to forecast precisely accurate costs, but rather to reveal the extent to which one alternative costs more or less than another**
- **It is often conducted with an effectiveness analysis to aid in selection of one alternative over others**

The general area we are here to discuss this morning is broadly classified as "cost analysis." At IDA we have about 100 people working in this area; 60 of them are members of the Research Staff, the rest are expert consultants who assist us from time to time.

Cost analysis is the process of estimating the individual and comparative costs of alternative ways of accomplishing an objective. Comparative costs are usually most important because they indicate the extent to which one alternative costs more or less than another. We often conduct a cost analysis in conjunction with an effectiveness analysis to assist our sponsors in selecting one system over another.

At IDA, we monitor cost research activities nationwide. We catalog research activities, making note of advances, and distribute this information to cost analysis organizations within the Department of Defense.

To assist our government sponsors in another way, we conduct, annually, a graduate-level course in cost analysis in cooperation with a local university in the Washington, DC, area. US government employees are invited to attend this course free of charge. Today's lecture is one of the lectures presented in the course. We would be happy to make other course lectures available to those of you who visit IDA next year.

## COST ANALYSIS COURSE

- Cost Analysis Overview
- Cost-Effectiveness Analysis
- Economics in Cost Analysis
- Estimating Relationships—Factors and Simple Models
- Cost Data
- Estimating Relationships—Complex Models
- Cost Progress Curves
- Production Rate Effects
- Software Cost Estimating
- Schedule Estimating
- Life-Cycle Costing
- Force Costing
- Case Studies

This slide lists the lectures in our course. We provide a thorough grounding in cost analysis, including economic considerations, and generally accepted procedures for conducting cost-effectiveness analyses. We teach how to develop both simple and complex cost-estimating models, and where to go to look for cost data.

The production rate effects lecture is the main source of the information I will present today. However, because this material requires an understanding of some of the material in the cost progress curve lecture, I will include a brief tutorial on cost progress curves as part of this lecture. I expect you all will be familiar with the concept of a cost progress curve. It is the same as a learning curve, where the time to perform some activity declines as the activity is repeated over and over. Cost progress curves depict the same sort of reductions, but they measure these reductions more generally in terms of costs, which could include time, dollars, or some other measure.

Other lectures cover software and schedule estimating and life-cycle costing, which covers all phases of a systems' life, including development, production, operation, maintenance, and removal from the force.

In our force costing lecture, we describe large-scale computer models that are used to estimate the costs of changes in force structure. Finally, students taking the course for credit are required to do a case study in which they estimate the cost of a system of their choice.

# OUTLINE

- **Issue**
  - **Problem**
  - **Example**
- **Cost Progress Curves**
  - **Theory**
  - **Practice**
- **Approach**
  - **Separate fixed and variable costs**
  - **Estimate variable costs**
  - **Allocate fixed costs**
- **Summary**

Now that introductory remarks are completed, I will begin the lecture on the subject of the cost effects of production rate changes. This slide shows an outline of the material I will cover.

First I will describe the nature of the problem and illustrate it with a simple example. Then, I will divert the discussion temporarily to provide a brief tutorial on cost progress curves. The ideas I will present are necessary to understand the rest of the presentation. I hope those of you who are familiar with cost progress curves will forgive and tolerate the digression.

Next, I will describe the reasons why costs change when production rate changes, and tell you how we at IDA estimate the cost effects of increasing or decreasing production rate. Our approach involves separating costs into fixed and variable components, then estimating the variable cost using a variation of the cost progress curve called the variable cost progress curve. After new variable costs have been determined, we allocate fixed costs, just as an accountant at the manufacturing plant would.

I will close with a summary that emphasizes several points worth remembering.

ISSUE

## ISSUE

- **Weapon system acquisition plans change frequently**
- **Cost estimates needed for alternatives**
- **Cost progress (i.e., learning) curves**
  - **commonly applied**
  - **not sensitive to rate**
- **Need improved method that accounts for both cost progress and production rate effects**

In the United States, the Department of Defense (DoD) buys weapon systems to equip its armed forces. Weapon system acquisition programs are planned and then budgeted. That is, the DoD proposes and the Congress approves purchases of certain quantities of systems year by year, and funding for these acquisition programs are included in the defense budget. Each year, system acquisition programs are reconsidered and reevaluated, and in many instances, plans change. Changes usually mean either decreases or increases in the number of systems to be purchased, year by year. Such considerations are sometimes driven by the need to reduce budgets. In other cases, increases in rate are needed to counter a rising threat.

The DoD is frequently faced with providing cost estimates for proposed changes in acquisition plans. The cost progress curve is the estimating method that is commonly used by defense cost analysts to develop such estimates. The method has many strengths and is easy to apply and understand. However, it also has shortcomings. One major problem with this method of estimating is that the results are not sensitive to changes in production rate.

We at IDA have provided our sponsors in the DoD with an improved method for estimating that captures the effects of cost progress and also the effects of a change in production rate. I will describe that method here today.

## SITUATION

- **Production in progress**
  - Tooling in place
  - Planned rate achieved
- **Consider deviating from planned rate**
- **Given**
  - Cost experience to date
  - Current plans
    - ◆ Quantities (i.e., lot sizes) year by year
    - ◆ Dollars budgeted year by year
  - Alternatives to current plan
    - ◆ Different quantities, year by year
- **Challenge: Estimate dollar amounts to be budgeted year by year for alternative quantities**

The problem setting is one in which a weapon system program is in production. The manufacturing plant has been established, tooling is in place, and production is in progress.

Then, the purchaser, the government, is considering a deviation from its original plan to purchase a specified quantity of systems year by year. Such considerations are sometimes driven by the need to reduce budgets.

In this situation, defense cost analysts use available information to produce estimates of the cost implications of changing the acquisition plan. Available information includes cost experience to date on this program and current plans that are included in budgets. Budget documents include the quantities, or annual lot sizes, to be purchased and also the dollars that are budgeted for each annual lot.

The cost analysts are advised of the changes under consideration. This information is usually provided in terms of changes in the quantities of systems to be purchased year by year.

The cost analysts' challenge is to estimate the costs of the proposed annual quantities. These dollar amounts will then be used in the DoD's budget planning documents.

# EXAMPLE

| | Year | Base Program | | Alternatives: Accelerate | | Alternatives: Stretch | |
|---|---|---|---|---|---|---|---|
| | | Q | $ | Q | $ | Q | $ |
| Past | 1 | 30 | 1,909 | | | | |
| | 2 | 70 | 2,469 | | | | |
| Present / Future | 3 | 100 | 2,461 | 200 | ? | 50 | ? |
| | 4 | 100 | 2,239 | 200 | ? | 50 | ? |
| | 5 | 100 | 2,028 | | | 50 | ? |
| | 6 | 100 | 1,911 | | | 50 | ? |
| | 7 | | | | | 50 | ? |
| | 8 | | | | | 50 | ? |
| | 9 | | | | | 50 | ? |
| | 10 | | | | | 50 | ? |

This example illustrates the issue and problem. We have a system acquisition program that has been ongoing for 2 years. That is, years 1 and 2 are past. We are about to begin year 3. The base program, that is, the program documented in current budget documents, is depicted in the shaded columns. Thirty units were produced in year 1; 70 units, in year 2; and we are about to start on the next lot of 100 in year 3. The current plan calls for producing 100 units per year for the next 4 years. The dollar amounts budgeted for each of these lots are listed in the second column.

The alternatives to the base program are shown in the columns to the right. There are two options to be considered in this example. The first is to accelerate the program by increasing production to 200 units per year and completing all production by the end of year 4. The second option is to stretch the program out over 8 additional years. This is accomplished by reducing the number of systems produced per year from 100 to 50.

The problem is to determine the dollar amounts to associate with the new annual quantities. That is, to fill in the question marks.

The quantities and dollars for the base program, those in the shaded area, can be used to develop a cost progress curve for the base program.

## Key Points

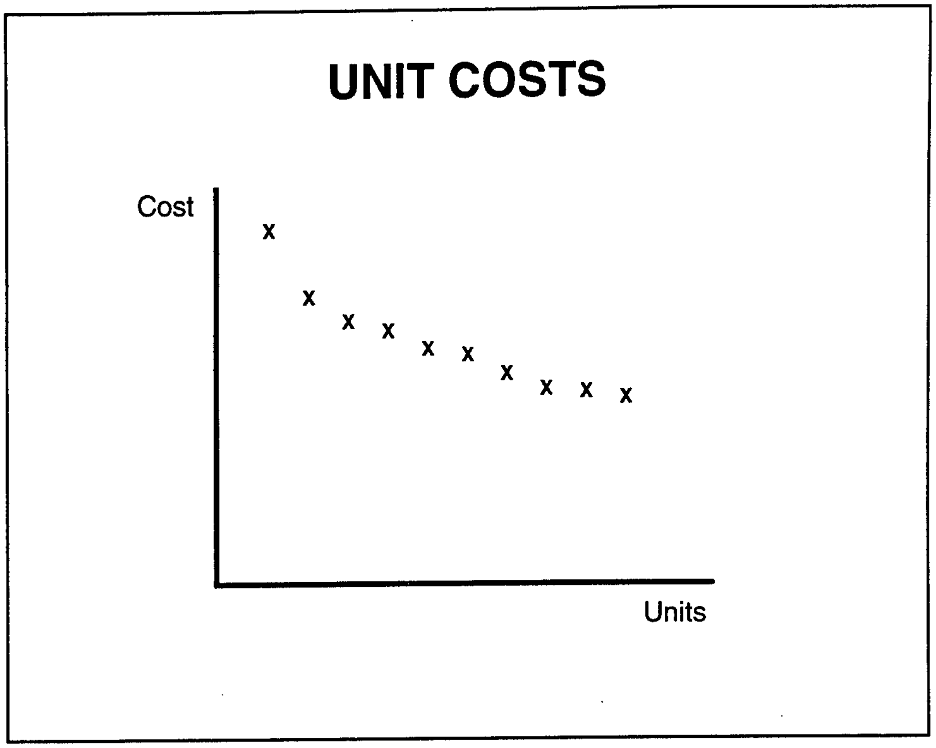
**Why do costs change when rate changes?**

- **Cost Progress**
  - **Applies to costs that vary with quantity**
    - ◆ **Independent of time periods**
  - **Can be estimated using a cost progress curve**
- **Rate (units per time period)**
  - **Applies to period (fixed) costs**
  - **Must be allocated within time periods**

Before describing the method for calculating the estimates for the revised quantities, I want to alert you to the main reasons why costs change when production rate changes. These points will be illustrated during the rest of the discussion.

The first reason why the cost of each lot changes is because the lot sizes change. That is, different numbers of units are produced in subsequent lots. Therefore, those costs that vary with quantity will change. We call costs that vary with quantity "variable costs." Such costs are independent of time periods. Examples of variable costs are the labor and materials required to produce the aircraft. Accountants refer to these costs as direct labor and direct materials. Variable costs can be estimated using a cost progress curve derived using only variable cost. This is called a variable cost progress curve.

The second reason why costs change is due to a change in rate or number of units produced per time period. The time period we are considering here is 1 year, which is a typical accounting cycle for US aircraft manufacturers. Costs that are not dependent upon quantity are called fixed costs. Examples of fixed costs include the salary of the president, the cost of security at the plant, and other routine functions that would continue unchanged even with wide swings in number of units produced in the plant. Such costs are referred to as period costs by accountants and are appropriately allocated to the units produced during each time period.

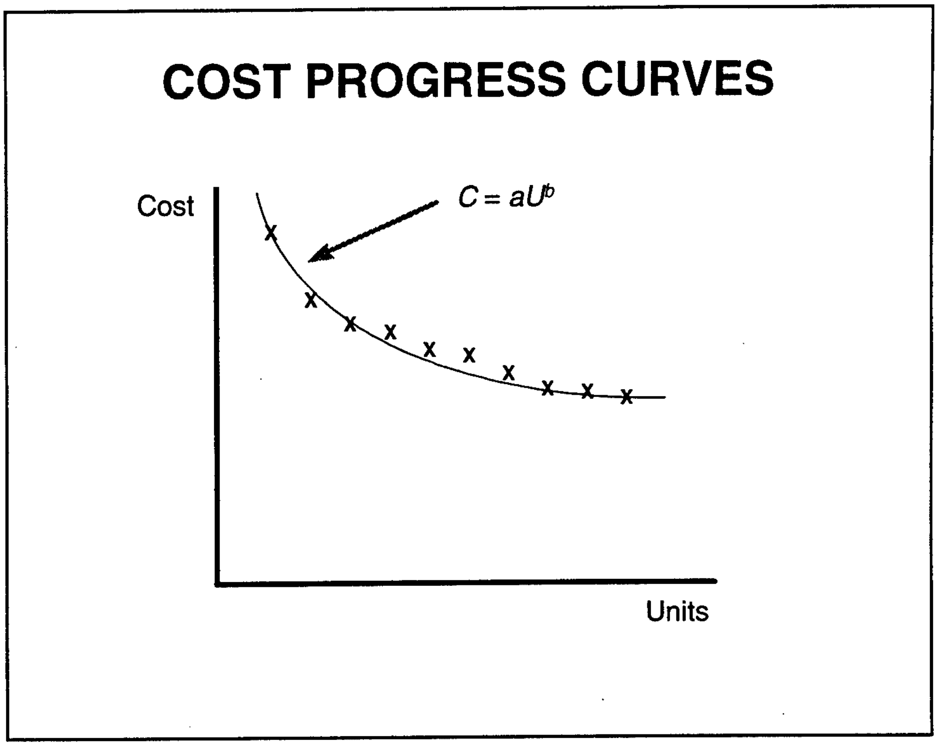



At this point, I will digress from the main topic and provide a short tutorial on cost progress curves.

Before and during World War II, the time and the cost of manufacturing aircraft dropped at a fairly regular but decreasing rate. For example, let the top x be the time to produce unit one and the second x be the time to produce unit 2, and so on. Note that the reduction in time between units 2 and 3 is less than between units 1 and 2. The same decreasing reduction relationship generally persists through subsequent units. The reduction in time is attributed to "learning," that is, finding ways to do things more efficiently. This process of learning was observed to persist through the entire life of production programs.

The same decreasing reductions were noted when cost data were plotted instead of time data. These reductions in unit costs were referred to as "cost progress."

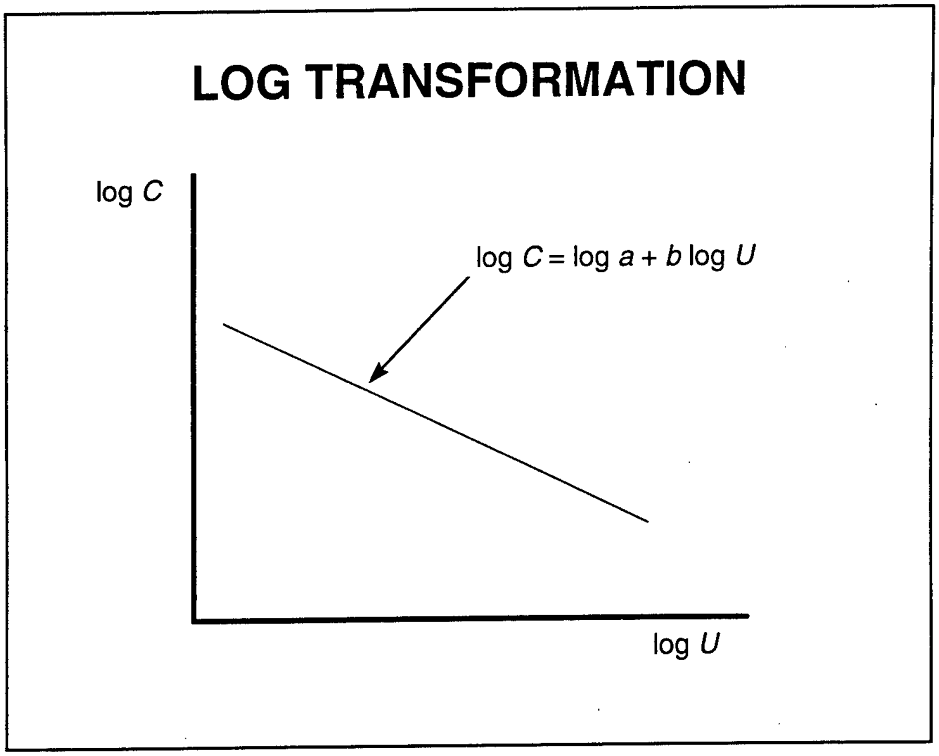
# COST PROGRESS CURVES




A regular pattern of cost reductions was observed in every aircraft production program. The regularity suggested these cost patterns could be modeled and used to forecast the costs of subsequent units. The model most widely used and accepted is depicted on this slide. It is a simple, single-variable power function in which cost $C$ is dependent only on the unit number. Given a handful of data points (that is, unit numbers and their associated costs), parameters $a$ and $b$ could be calculated such that the curve was a "best fit" to the data.

Other mathematical models have been used, such as the exponential function; however, the power function has persisted as the model of choice for cost analysis purposes.

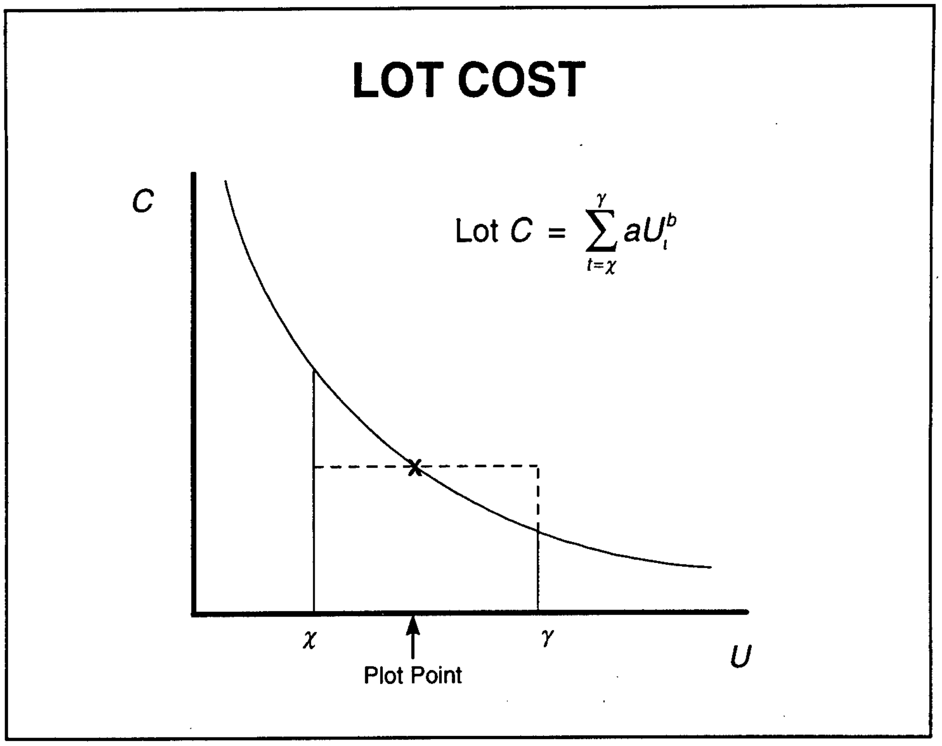
The power function depicts a regular reduction in cost as unit number increases. That is, as unit number doubles, say from unit 1 to unit 2, or from unit 2 to unit 4, the cost declines by a fixed percentage. If that percentage were, say, 80%, then if unit one had a cost of \$100, unit 2 would cost \$80, unit four would cost \$64 (80% of 80), and unit 8 would cost about 51 (80% of 64). This rate of cost progress (or reduction in cost as quantity doubles) is determined by the size of parameter $b$, so $b$ is referred to as the rate parameter of the curve and depicts the rate at which costs decline as units increase. Note that if we let $U$ equal one, representing unit 1, then $C$ equals $a$. That is, parameter $a$ represents the cost of the first unit and determines the height of the curve.




US cost analysts usually fit cost progress curves using the log transformation form shown here. Under the transformation, the equation is linear in *U*. Parameters retain their meanings, however, the parameter *b* is more easily understood in this form. Note that *b* is the slope of the straight line. Because of the widespread use of this form of the curve, *b* has become known as the "slope parameter." A steeper slope indicates faster cost progress, and a shallow slope means slower cost progress.

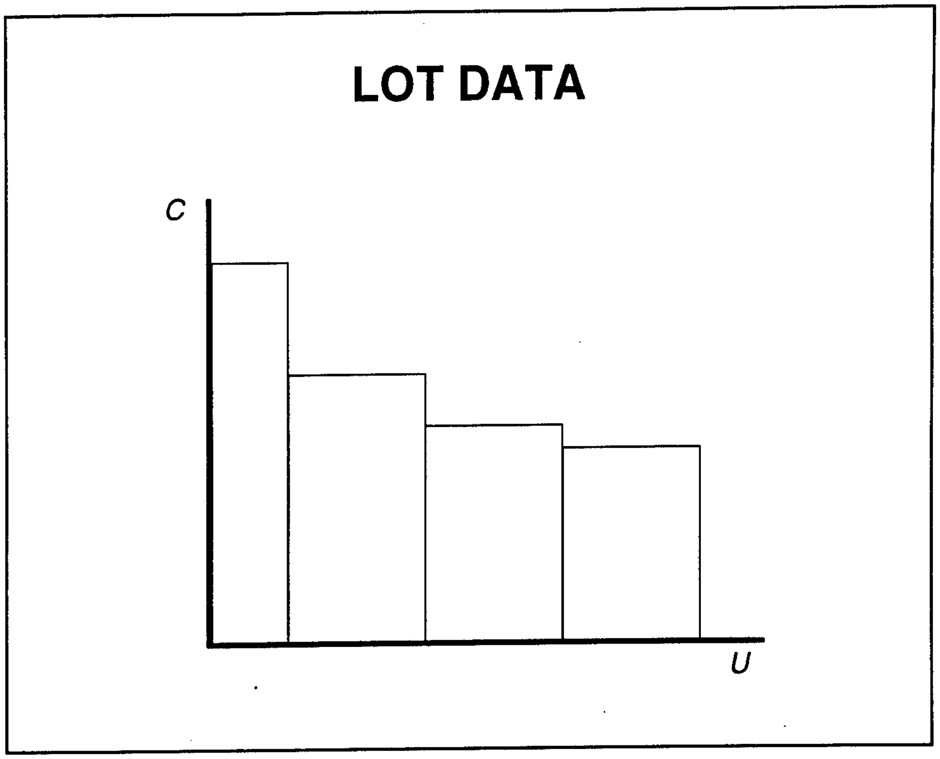
At IDA, we have studied the effect of technology on the slope of cost progress curves by analyzing values of *b*'s associated with curves that model operations with different levels of technology. Our findings show that labor-intensive manufacturing is associated with steeper sloping curves and machine-intensive manufacturing (using more machines in place of labor) is associated with shallower curves. Further, as manufacturers replace people in the production process with machines, the slope of the curve becomes flatter.

Cost analysts develop cost progress curves for estimating purposes by selecting a value for *b* (and therefore the slope) that represents the technology used in the manufacturing process, and estimating the cost of one unit—any unit. We usually estimate the cost of unit 100 for aircraft and unit 1,000 for missiles. The resulting curve is obtained by drawing a straight line with the slope determined by parameter *b* through the plot point of the estimated unit cost.



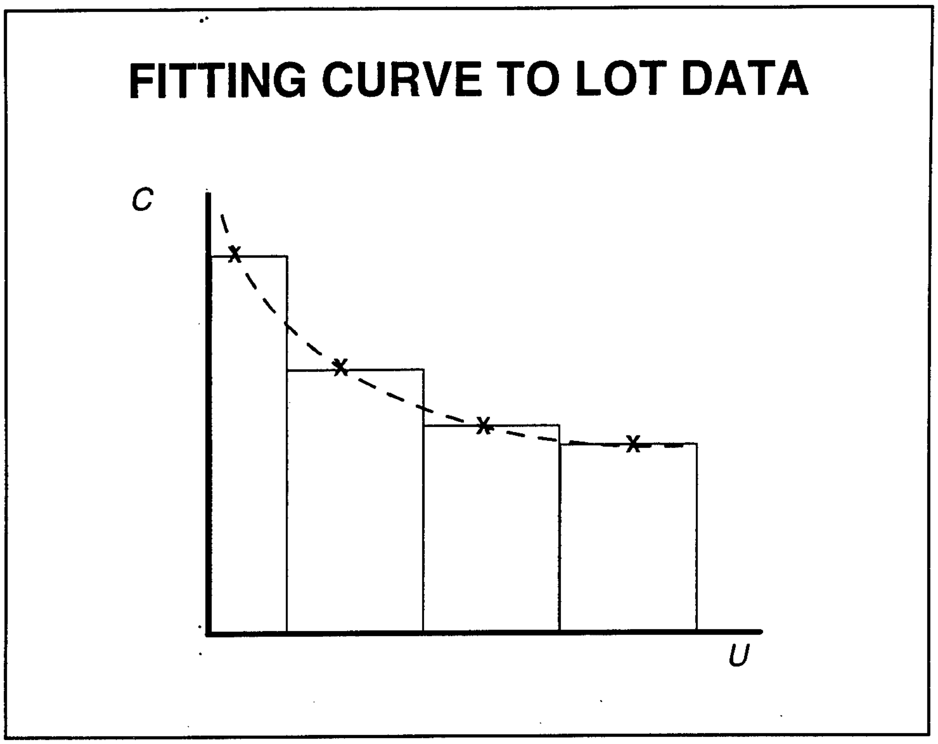

Aircraft are usually produced in lots of say, 20, 50 or 100 units. The cost progress curve can be used to estimate the cost of a lot by integrating the curve across the unit numbers in the lot, thereby finding the area under the curve between the starting unit and the ending unit in the lot. That calculation is equivalent to adding up the costs of the individual units in the lot, as depicted in the summation shown on the slide.

Note that lot costs can be depicted another way—as a rectangle having the same area as the area under the cost progress curve. The height of this rectangle is the average unit cost of units in the lot, and the width is the number of units in the lot. The plot point for the average unit cost is not in the center of the rectangle, but rather to the left of the center. This is because of the changing slope of the cost progress curve. There is a standard procedure for calculating the plot point for a given lot, but I will not address it in this lecture. The calculation involves simple arithmetic.




I went through that discussion on lot costs because US defense analysts use lot costs to develop cost progress curves because those are the only costs available to them. This is because manufacturers record the costs of lots rather than unit costs when manufacturing.

This slide shows the type of data a defense analyst might obtain from a manufacturer on the production of four lots of aircraft. The height of the rectangles reflect the average unit costs of the lots, and the width of the rectangles reflect the number of units in the lots.




The defense analyst uses lot data to estimate the parameters of a cost progress curve by plotting the average unit costs of each lot, shown here as x's, and then fitting a power function to the plotted points.

During the remainder of this presentation, when I say that we can fit a cost progress curve to some specified set of data, the data will consist of lot quantities and lot costs. The procedure implied by such statements is the procedure depicted here on this slide.

This ends my short tutorial on cost progress curves.

## CPC ESTIMATES

| Year | Base Program Q | Base Program $ | Alternatives: Accelerate Q | Accelerate $ | Stretch Q | Stretch $ |
|---|---|---|---|---|---|---|
| 1 | 30 | 1,909 | | | | |
| 2 | 70 | 2,469 | | | | |
| 3 | 100 | 2,683 | 200 | 4,945 | 50 | 1,415 |
| 4 | 100 | 2,262 | 200 | 3,892 | 50 | 1,268 |
| 5 | 100 | 2,026 | | | 50 | 1,168 |
| 6 | 100 | 1,866 | | | 50 | 1,094 |
| 7 | | | | | 50 | 1,037 |
| 8 | | | | | 50 | 989 |
| 9 | | | | | 50 | 950 |
| 10 | | | | | 50 | 916 |
| Totals: | 400 | 8,837 | 400 | 8,837 | 400 | 8,837 |

Now back to the problem of estimating the effects of a change in production rate. Previously I showed a slide like this that had question marks in the spots where estimates were needed. This slide shows the numbers that would be calculated if we developed a cost progress curve using the cost and quantity data in the first two columns, corresponding to our base program, and applied that curve to estimate the costs of the different lots listed to the right.

The first thing to note is that the total cost for 400 additional aircraft is the same for all three options. This should be no surprise, as the cost progress curve simply adds up the costs of units, independent of rate. Note that the cost of 200 units in year 3 under the accelerate option is simply the sum of the costs of 100 in year three and 100 in year 4 under the base case.

However, both intuition and experience tell us that the costs of these three options should be different, not the same. In the accelerate case, production occurs for only half the time of the base case. We would expect the total cost to be less than the base case because the fixed costs of running the plant are incurred for only 2 years rather than 4. The opposite is true of the stretch case, where the fixed costs associated with the plant are borne for 8 years. This should result in a greater allocation of fixed costs and correspondingly higher unit and total costs.

# APPROACH

## APPROACH

- **Separate fixed and variable costs**
  - **Plant**
  - **Program**
- **Estimate variable cost for alternative quantities**
  - **Variable cost progress curve**
- **Allocate fixed costs**
  - **Proportional to variable costs**

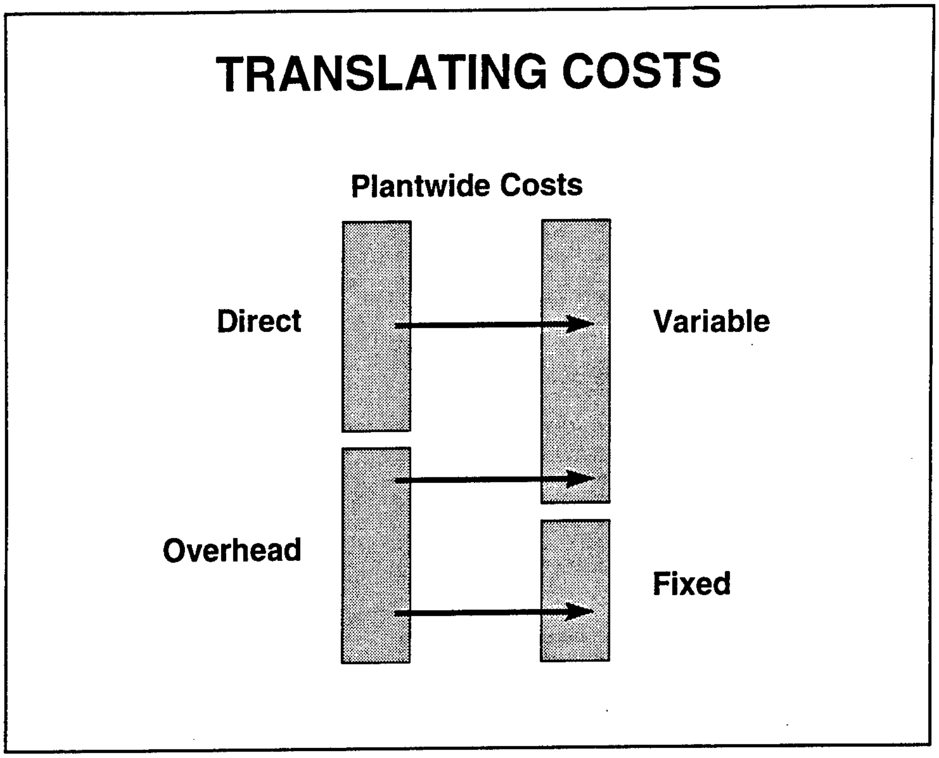
I mentioned that IDA provided the DoD with an improved method for estimating the cost of a change in production rate. The approach we use is to separate total costs into their fixed and variable components and estimate each piece separately for each production lot.

IDA has studied US aircraft manufacturers for more than 12 years and has obtained detailed cost information on manufacturing operations at their plants. We use these data to separate fixed and variable costs at each plant. We use a variety of techniques to do this, and I will give you the general idea in a moment.

Once total cost is separated at the plant level, we assume the same split is appropriate for the individual programs being manufactured in the plant.

Using plantwide relationships, we separate out the variable costs of the program we are interested in, and use that data to develop a cost progress curve that represents only variable costs. This curve is referred to as a "variable cost progress curve." Once the curve is available, the variable costs of alternative lot sizes are calculated.

The final calculation is to allocate plantwide fixed costs to program lots within time periods, just as an accountant at the plant would do. We make this allocation in proportion to the variable costs associated with all programs in the plant.

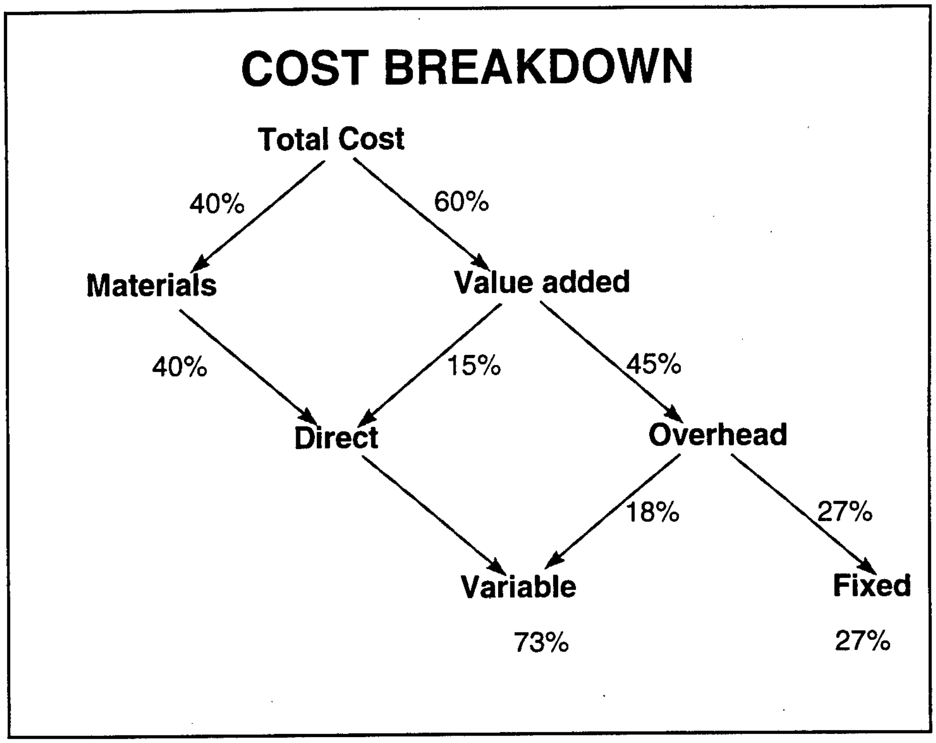



I will briefly describe how we go about separating fixed and variable costs at a particular plant.

We receive detailed data from manufacturers in the same form as they maintain it in their accounting systems. Unfortunately, manufacturers do not record costs in the categories we want—that is, fixed and variable categories. They record costs as either direct or overhead. Direct costs are those that can be associated with a specific cost objective, such as a lot of aircraft. Overhead costs cannot be associated with any particular cost objective. Rather they pertain to all activity in the plant and are allocated to activities within the time periods in which they are incurred. We have observed that some portion of overhead varies with output, and the remainder does not.

We view all direct costs as variable. Then, using regression methods, we separate overhead costs into two parts, one that varies with output, and the other part that does not. This latter part is the fixed component of costs that must be allocated across all programs in the plant by time period.

The variable part of overhead is combined with direct costs to arrive at plantwide variable costs. We use this split at the plant level to separate program costs into fixed and variable components.

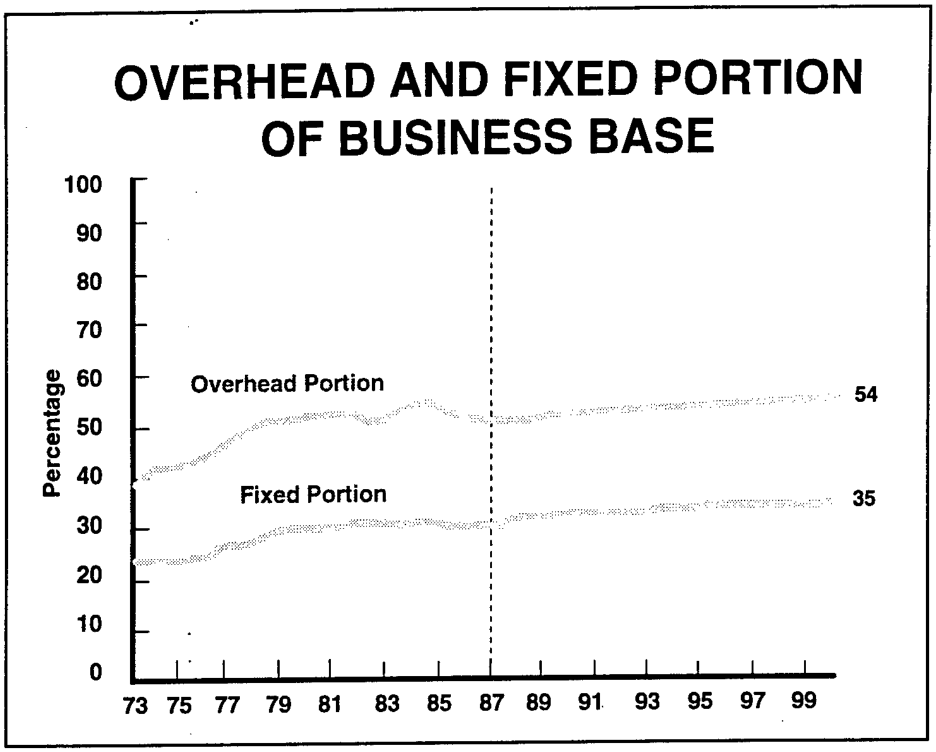



This slide shows part of the results of a study IDA conducted in 1987. We aggregated and analyzed costs reported by the largest aircraft manufacturers in the US, and separated these aggregated costs as shown.

Total costs consist of about 40% materials and about 60% value added. Value added consists of direct labor costs and associated overhead. Of that 60%, about 15% is direct labor, and 45% overhead. When direct labor costs are combined with materials, also considered direct costs, the sum is about 55% direct costs, leaving about 45% of costs as overhead.

We applied the technique described on the last slide to separate overhead at these plants into fixed and variable components. In aggregate, these manufacturers had about 73% variable costs and about 27% fixed, as of 1987.

We have updated that study since then, and the split between direct and overhead has shifted. At present, more than half of US aircraft manufacturing costs consist of overhead.




IDA conducted a related study on trends in overhead cost at about the same time—1987. This slide shows one of the findings.

As I mentioned, overhead costs were shown to be increasing from about 40% up to near 50% over our study period. These costs were projected to increase modestly over the next few years. Experience has borne this out.

Fixed costs also were shown to be trending upward through this period. We projected that this component of cost would continue to increase. The reason for the increase had to do with increases in automation at these facilities. That is, people were being replaced with labor-saving machines, and the costs of facilitizing tended to increase both overhead costs and the fixed component of costs.

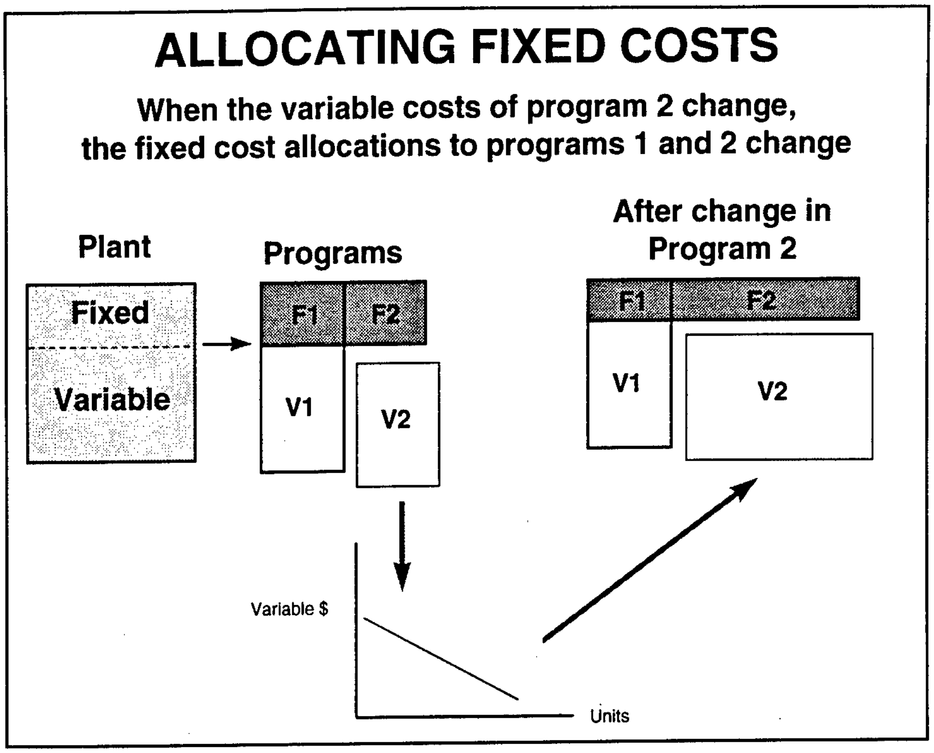
## ESTIMATING VARIABLE COSTS

| Year | Base Program | | | | Alternatives: Accelerate | | | | Alternatives: Stretch | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q | Var'l | Fixed | Total | Q | Var'l | Fixed | Total | Q | Var'l | Fixed | Total |
| 3 | 100 | 2,007 | 634 | 2,461 | 200 | 3,701 | | | 50 | 1,057 | | |
| 4 | 100 | 1,694 | 545 | 2,239 | 200 | 2,919 | | | 50 | 949 | | |
| 5 | 100 | 1,519 | 510 | 2,029 | | | | | 50 | 875 | | |
| 6 | 100 | 1,400 | 511 | 1,911 | | | | | 50 | 820 | | |
| 7 | | | | | | | | | 50 | 777 | | |
| 8 | | | | | | | | | 50 | 742 | | |
| 9 | | | | | | | | | 50 | 713 | | |
| 10 | | | | | | | | | 50 | 687 | | |
| Tota | 400 | 6,620 | 2,220 | 8,820 | 400 | 6,620 | | | 400 | 6,620 | | |

This example slide shows the total costs for the base program separated into fixed and variable components. Given this separation, we are now in position to estimate the variable costs of our alternative programs that call for accelerating or stretching production.

Values in the shaded columns can be used to develop a variable cost progress curve for this program. That curve can be applied to estimate the variable costs associated with the lots in the other cases. Recall, variable costs vary with quantity, not with time periods. The variable cost progress curve redistributes the variable costs of units to the lots in which they end up under each option, without changing total variable costs. For example, the variable costs of the year 3 lot in the accelerate case is the sum of the variable costs of the lots for years 3 and 4 in the base case. Also note that the variable cost totals for all three cases are the same.

What is left for us to do is to allocate fixed costs to these lots.




This slide shows how fixed costs are allocated within time periods, as an accountant at the plant would do it.

The rectangle at the left shows total costs at the plant separated into fixed and variable categories. The figure to the right of that shows the same separation of fixed and variable costs at the program level. We assume there are two programs in progress at this plant and that the plant is considering increasing the annual lot size associated with program 2. Note that fixed costs, shown in the darker rectangles, are proportional to the variable costs of the programs.

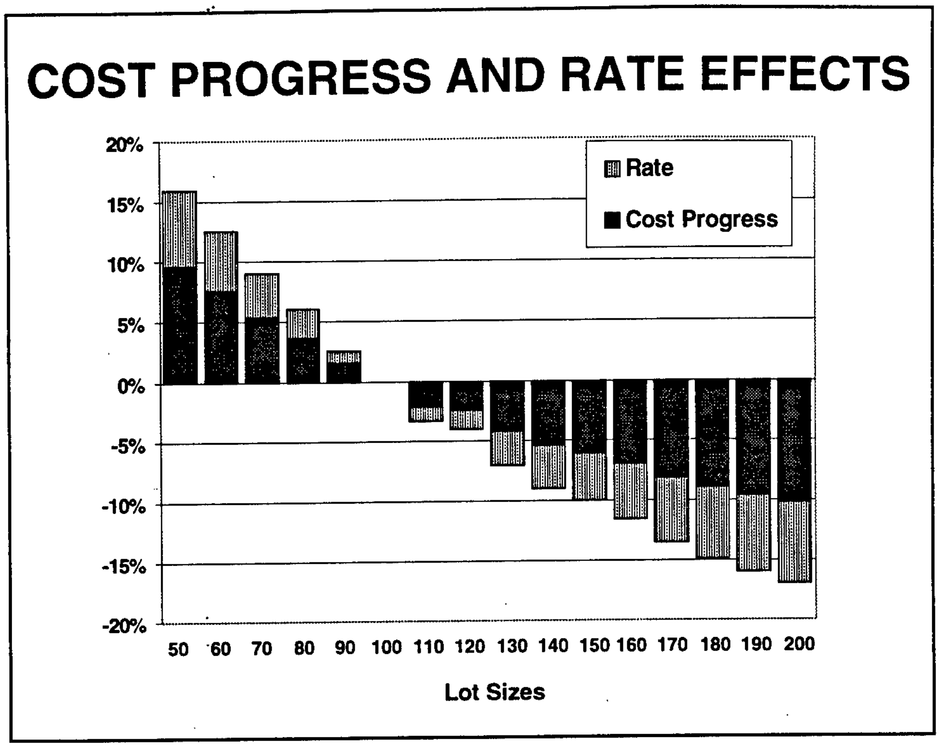
The first step is to develop a variable cost progress curve using the variable costs associated with program 2, labeled V2 in the slide. We then calculate the increased variable costs associated with the new larger lot size.

The figure to the right shows how fixed costs are reallocated to programs, after the change in variable costs for program 2. The total amount of fixed costs is the same (the areas F1 and F2 combined in each case is the same). However, the amounts allocated to programs 1 and 2 have changed. Since program 2 now represents a larger portion of total variable costs, it receives a greater allocation of fixed costs. Also note that the average unit costs for program 2 have declined. The average costs are depicted as the height of the combined variable and fixed rectangles. It is worth noting that even though program 1 did not change, the fixed cost allocation to program 1 changed as a result of the change to program 2.

# TOTAL COSTS

| Year | Base Program | | | | Alternatives: Accelerate | | | | Alternatives: Stretch | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q | Var'l | Fixed | Total | Q | Var'l | Fixed | Total | Q | Var'l | Fixe | Total |
| 3 | 100 | 2,007 | 634 | 2,461 | 200 | 3,701 | 1,034 | 4,735 | 50 | 1,057 | 369 | 1,426 |
| 4 | 100 | 1,694 | 545 | 2,239 | 200 | 2,919 | 896 | 3,815 | 50 | 949 | 345 | 1,294 |
| 5 | 100 | 1,519 | 510 | 2,029 | | | | | 50 | 875 | 325 | 1,200 |
| 6 | 100 | 1,400 | 511 | 1,911 | | | | | 50 | 820 | 308 | 1,128 |
| 7 | | | | | | | | | 50 | 777 | 294 | 1,071 |
| 8 | | | | | | | | | 50 | 742 | 283 | 1,025 |
| 9 | | | | | | | | | 50 | 713 | 275 | 988 |
| 10 | | | | | | | | | 50 | 687 | 276 | 963 |
| Total | 400 | 6,620 | 2,220 | 8,820 | 400 | 6,620 | 1,930 | 8,550 | 400 | 6,620 | 2,475 | 9,905 |

After making the calculations depicted on the last slide for all lots, we can fill in the shaded spaces on this slide. We now have new estimates for variable costs for lots; however, the total variable cost for each option is the same, 6,620. New allocations of fixed costs are shown for both alternatives. The option to accelerate production received a reduced allocation of fixed costs because manufacturing occurred for only 2 years, rather than 4 as in the base case. Fixed costs increased for the option to stretch production because manufacturing activities were extended for 4 additional years, during which fixed costs continued to be allocated to this program.




Using the method just described, the change in cost associated with a change in production rate can be separated into two distinct components, one due to cost progress, the other due to rate.

The graph here shows how much unit costs change as lot sizes change in our example. Lot sizes are shown across the bottom of the figure. The change in unit cost is measured on the y-axis. As lot size increases, say from 100 to 200, unit costs decline by about 17%. About 10% of that is due to cost progress, and the rest is due to the reallocation of fixed costs.

Also, as lot size declines from 100 to 50, unit costs increase by about 16%. Of that, about 9% is due to cost progress, and the remaining 7% is due to rate.

# SUMMARY

## SUMMARY

- **Increases in rate tend to lower unit costs**
- **Decreases in rate tend to increase unit costs**
- **Costs change because of:**
  - ***Cost Progress***
    **A change in quantity of a contract/lot changes the position of the average unit cost for that lot on the cost progress curve**
  - ***Rate (units per time period)***
    **A change in direct expenditures during a period results in a change in allocation of overhead (the fixed portion of overhead) for that period**

The key points to remember are as follows: (1) increases in production rate tend to lower unit costs, and (2) decreases in production rate tend to increase unit costs. In very unusual circumstances, this may not turn out to be the case. However, such a finding would be unexpected.

As I have stressed several times, the reasons why costs change when production rate change are: first, cost progress and second, rate. Each effect can be measured separately, as illustrated in the last slide.

Defense analysts in the US DoD use the method described here when reestimating acquisition programs. I hope you find this method useful.

Thank you for your attention.

# REFERENCES

# REFERENCES

[1] Stephen J. Balut and James D. McCullough, "Trends in a Sample of Defense Aircraft Contractors' Costs," Institute for Defense Analyses, Document D-764, August 1990.

[2] Stephen J. Balut, "Defense Contractor Overhead Costs and Trends," a presentation at the October 29–November 1, 1995, INFORMS National Meeting, October 1995.

**UNCLASSIFIED**

| REPORT DOCUMENTATION PAGE | | | *Form Approved OMB No. 0704-0188* |
|---|---|---|---|

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 2220-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

**1. AGENCY USE ONLY (Leave blank)**

**2. REPORT DATE**
October 1996

**3. REPORT TYPE AND DATES COVERED**
Final Report, Aug 1996–Oct 1996

**4. TITLE AND SUBTITLE**
Cost Effects of a Change in Production Rate

**5. FUNDING NUMBERS**
DASW01 94 C 0054

CRP 9001-717

**6. AUTHOR(S)**
J. Richard Nelson and Stephen J. Balut

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22311-1772

**8. PERFORMING ORGANIZATION REPORT NUMBER**
IDA Document D-1926

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22311-1772

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12A. DISTRIBUTION/AVAILABILITY STATEMENT**
Suitable for public release; distribution unlimited.

**12B. DISTRIBUTION CODE**

**13. ABSTRACT *(Maximum 200 words)***

Several IDA representatives visited the China Institute of Aeronautic Systems Engineering in October 1996 with the purpose of providing the Institute with an estimate of the cost to produce an 100-passenger aircraft. As a way of strengthening IDA's relationship with the Institute during the visit, IDA delivered a lecture on cost estimating and analysis. This document is an annotated version of that lecture. It gives background information on the areas of research IDA pursues before focusing attention on the area of cost analysis. The cost effects of production rate changes serves as an example. The problem is illustrated using the simple example of a 6-year system acquisition program about to begin its third year. The problem is to estimate the annual costs of two alternative programs, one that accelerates the production rate and one that stretches it. The solution involves separating costs into their fixed and variable components before estimating the variable costs for the new program and allocating fixed costs. Before solving the problem, the lecturer gives a short tutorial on cost progress curves.

**14. SUBJECT TERMS**
Cost Analysis; Cost Estimates; Production Rate; Learning Curves

**15. NUMBER OF PAGES**
37

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | SAR |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

**UNCLASSIFIED**