

NASA TECHNICAL MEMORANDUM

NASA TM X-73373

(NASA-TM-X-73373) MANUFACTURING COMPLEXITY
ANALYSIS (NASA) 19 p HC A02/MF A01 CSCL 13H

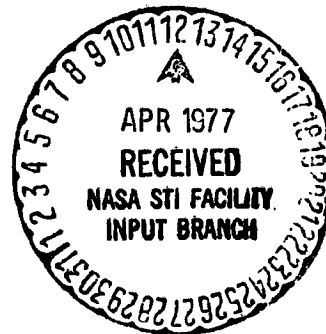
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MANUFACTURING COMPLEXITY ANALYSIS

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February 1977



NASA

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1. Report No. NASA TM X-73373	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Manufacturing Complexity Analysis		5. Report Date February 1977	
		6. Performing Organization Code	
7. Author(s) Dr. Leon M. Delionback		8. Performing Organization Report No.	
		10. Work Unit No.	
9. Performing Organization Name and Address George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		11. Contract or Grant No.	
		13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code	
		15. Supplementary Notes Prepared by Systems Analysis and Integration Laboratory, Science and Engineering	
16. Abstract <p>This report explains the principle of complexity analysis and its special relationship with learning/cost improvement curve theory.</p> <p>A "bottoms up" approach for the analysis of the complexity of a typical system is presented. Starting with the subsystems of an example system, the step-by-step procedure for analysis of the complexity of an overall system is given. The learning curves for the various subsystems are determined as well as the concurrent numbers of relevant design parameters. Then trend curves are plotted for the learning curve slopes versus the various design-oriented parameters, e.g. number of parts versus slope of learning curve, or number of fasteners versus slope of learning curve, etc.</p> <p>Representative cuts are taken from each trend curve, and a figure-of-merit analysis is made for each of the subsystems. Based on these values, a characteristic curve is plotted which is indicative of the complexity of the particular subsystem (Figure-of-merit versus learning curve slope). Each such characteristic curve is based on a universe of trend curve data taken from data points observed for the subsystem in question. Thus, a characteristic curve is developed for each of the subsystems in the overall system.</p> <p>A composite complexity analysis is performed to determine the manufacturing complexity for the overall system. A procedure is outlined to define the steps in computation for this value (along with an illustrative example).</p> <p>In the discussion a narrative description is given for the limitations in scope of the manufacturing complexity analysis with examples of some of the cost elements that are not included.</p>			
17. Key Words (Suggested by Author(s)) "Bottoms up" Approach Manufacturing Complexity Design Complexity Design Configuration Learning Curve		18. Distribution Statement Unclassified -- Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 19	22. Price NTIS

PREFACE

The manufacturing complexity concept embodies the learning/improvement curve principle to reduce the cost for a specific number of units in a production run.

The learning/improvement concept results in a factor, expressed as a decimal, i. e., .75, .80, .85, or .90, that is used to reduce the cost value of the first unit of production. Since the cost of the number one or first unit (TEU) will not include any learning or improvement savings, this value is generally accepted as the optimum cost value in the sequence. Thus the first unit in a production sequence will generally represent the maximum cost, and as time passes each unit manufactured after the first unit will indicate a cost reduction or savings. The magnitude of this savings will be represented by the slope or steepness of the learning curve. If there is no learning or cost improvement, the cost of unit number 1 will simply remain constant with a slope of 1.0 or 100 percent for the learning curve.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
TREND CURVE ANALYSIS	3
FIGURE-OF-MERIT ANALYSIS	4
COMPOSITE COMPLEXITY ANALYSIS	7
COMPUTATION OF THE VALUE IN DOLLARS OR MANHOURS FOR THE OVERALL SYSTEM	9
DISCUSSION	9
BIBLIOGRAPHY	11

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Trend curve for total number of fasteners	2
2.	Sample — trend curve data taken from cuts	4
3.	Sample — characteristic curve	5
4.	Sample diagram	6
5.	Sample	7

LIST OF DEFINITIONS

- Manufacturing Complexity** This term refers to all of the cost elements which affect or influence the cost of manufacturing of a unit of production. It may be represented by the learning curve slope.
- Design Complexity** This form of complexity has to do with features or parameters of an engineering design which contribute to its complexity. Examples of such features which tend to increase the measure of design complexity are such aspects as total number of parts, number of fasteners, or number of subassemblies. Others might include the number of different steps or processes required to fabricate, assemble, or to inspect.
- Design Configuration Type (DCT)** A design configuration type is used to designate the category or generic class of system configurations for which the technical and cost elements could be expected to be typical. Examples of DCT's would be solid propellant boosters, nuclear reactors, army tanks, or unmanned space vehicles. Such examples represent distinct examples of large system types, each of which is made up of a unique set of subsystems and hardware components. Many of the lower level subsystems will be similar and will exhibit similar learning curve slopes.
- Factor** This term can be considered a synonym for parameter or feature when used in the text.
- Learning Curve (LC)** A learning curve is a graphical plot on either cartesian or double logarithmic paper that represents the rate of learning progress by humans, usually in the performance of some task or group of tasks. In general, these curves will approximate a decreasing exponential shaped

LIST OF DEFINITIONS (Concluded)

Learning Curve (LC) (Concluded)

curve, if the progress is normal. In the trade, the term "learning curve" has been used interchangeably with such terms as progress function or cost improvement curve. It should be recognized that the latter terms include such aspects as tooling changes, design configuration changes, etc., as well as the human learning element.

Log Linear

This term is often used to describe learning/cost improvement curves which are plotted on double logarithmic paper. In general, such curves appear as straight lines. This greatly simplifies determination of the slope and will make these curves easier to plot.

TECHNICAL MEMORANDUM X-73373

MANUFACTURING COMPLEXITY ANALYSIS

INTRODUCTION

The recognition of the special relationship that the complexity of a particular design has with the variation of the unique design features and/or parameters of a system is the thesis for this approach. The various countable parameters of the particular design will be enumerated and tabulated such that trends will be established for the improvement/learning curve aspects of the subsystems of the overall or total system. For example each of the countable design parameters such as number of fasteners, total number of parts, or number of subassemblies, etc., is enumerated by examination of the detail design drawings. Each of these parameters will in turn be plotted against the corresponding learning curve values as observed from data taken to plot a trend curve. (These trend curves are plotted on arithmetic coordinates in Figure 1.)

This same method will be used for each of the prime subsystems of the system in question, and those values thus obtained will be embedded in a figure-of-merit for the prime subsystem in question (as outlined here). The learning curve slope of the overall system will be determined from this figure-of-merit value. For purposes of calculation of the final composite for the overall composite learning curve value, such functions as the final assembly will be treated as one of the subsystems of the subject system.

This slope of the learning curve is considered to be a principal indicator of the complexity of any prime subsystem. Learning curves for the other subsystems that comprise the total or overall system will be determined in a similar manner. Each subsystem will utilize trend curve methodology to specify the slope for particular learning/improvement curve.

Briefly the complexity of any system will vary inversely with the slope of the log-linear learning curve. The steeper the slope of the curve the less complex or simpler will be the final assembly or combination of parts and

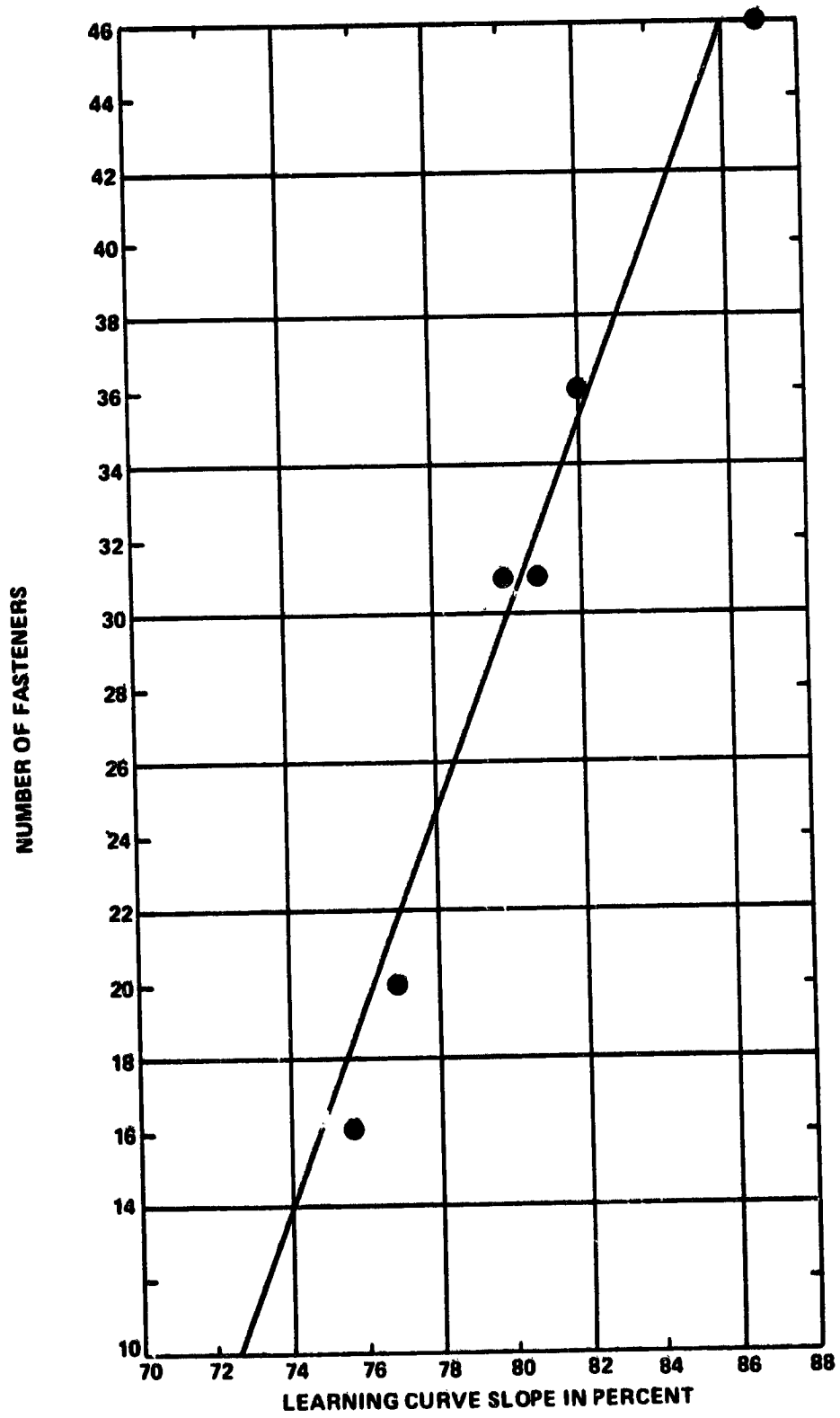


Figure 1. Trend curve for total number of fasteners.

components it represents (or vice versa). The value of the total system learning curve slope may be computed by using the method outlined in TM X-64968.¹

TREND CURVE ANALYSIS

Trend curves based on observed data are plotted on arithmetic coordinates to establish a trend relationship. As is illustrated in Figure 1 the data values for certain design-oriented parameters are utilized: (a) time to complete first assembly, (b) number of subassemblies, (c) number of fasteners, and (d) total number of parts. As in Figure 1 the relationship will usually result in an increasing trend line from left to right, as the quantity of the different design features increases. The data values will consist of learning curve slopes taken for each of the subassemblies, while at the same time observing the design-oriented parameters as previously itemized. A minimum of six data values will be collected for each of the parameters. A set of such design-oriented parameters will be collected for each subassembly in question, i. e., mechanical subassembly, electrical subassembly, etc. Therefore, a universe of trend curves will be established for each of the prime subassemblies in a typical system; i. e., there will be a set of trend curves for each subassembly or prime element. Each of the design-related parameters will be considered as "factors" in the manufacturing complexity of a particular system. The information that is collected relative to the various systems or subsystems will be plotted as learning curve trend lines to measure the relative sensitivity of the various subparameters to the slope of the learning curve (Fig. 1).

Collection of data must be accomplished for each of the design-oriented factors and for any others found to have some relation to the complexity of the specific assembly or system. Also of importance is the level of the assembly. It will be necessary for all of the collected values to be at the same level, or be assumed as such, to compute the appropriate complexity value whether it is a system, subsystem, or component part. After collection of the various data and plotting the appropriate trend curves, a decision point is reached to use or not use each of the parameters based on its relative sensitivity and its being representative of the system in question. If a design-oriented parameter is found not to be representative of the overall system, it is simply omitted from further consideration.

1. Dellonback, Leon M.: Guidelines for Application of Learning/ Cost Improvement Curves. NASA Technical Memorandum TM X-64968, October 1975.

FIGURE-OF-MERIT ANALYSIS

After completing the trend curve plots for the various design-oriented parameters, or factors, a selection is made of a set of factors which are representative of the overall assembly design. For example, a set of design-oriented factors for a typical mechanical assembly might include the following:

- a. Number of parts
- b. Number of fasteners
- c. Number of subassemblies.

Each set thus chosen would be indicative of the particular type of assembly being investigated. The set chosen for an electrical assembly would be different, depending on the nature of those factors found by a trend curve analysis to be representative of the overall system.

For each overall system a series of cuts are taken from each trend curve at several learning curve slopes and for each of the selected trend curves. For example (Fig. 2), cuts were taken at intervals of 3 percent in an example illustrated by Dellonback.² These cuts illustrated a learning curve range of 72 percent to 90 percent. These values are combined in a multiplicative figure-of-merit time series relationship illustrated in Figure 2.

SLOPE %	F ₁	F ₂	F ₃	F ₄	TOTAL Q _F	LOG Q _F
72	10	1.5	8.0	8.0	960	2.98227
75	35	3.7	16.0	24.0	49,730	4.69660
78	61	5.86	24.3	40.7	353,530	5.54843
81						

Figure 2. Sample — trend curve data taken from cuts.

2. Dellonback, Leon M.: A Design-Oriented Prediction Model for Learning Rates of Individual Mechanical Assembly Tasks. Doctoral Dissertation, Oklahoma State University, Stillwater, Oklahoma, May 1972.

$$Q_F = F_1 \times F_2 \times F_3 \times F_4 \dots F_n$$

From the sample table in Figure 2

$$\text{Log } Q_F = \text{Log } F_1 + \text{Log } F_2 + \text{Log } F_3 + \text{Log } F_4 = \underline{2.98227 \dots}$$

and from the table of cuts of the trend curves, the computed values for the figure-of-merit are plotted in Figure 3, one point for each cut.

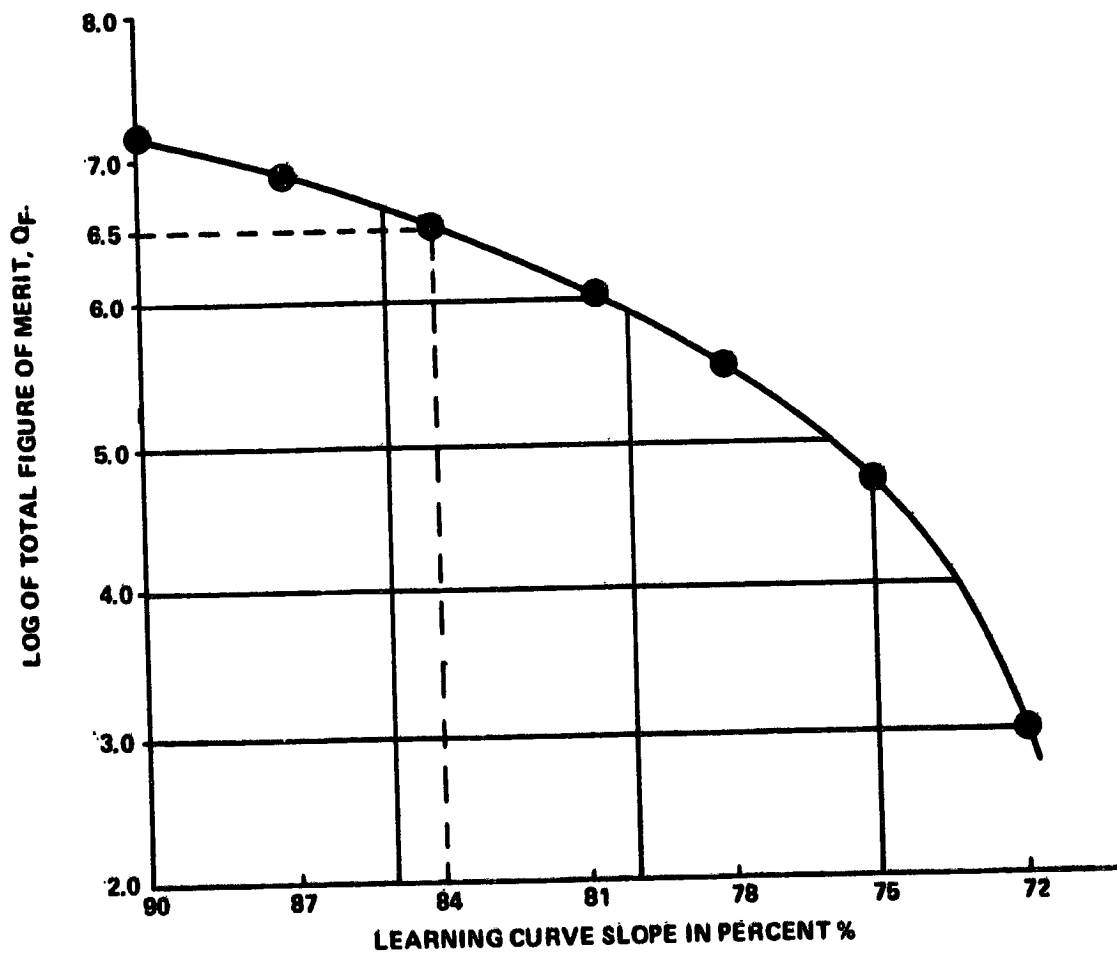


Figure 3. Sample — characteristic curve.

Based on the illustrative information given in Figure 2, a characteristic curve (Fig. 3) is developed for each subsystem or assembly type. Each curve is based on a universe of trend curve data taken from actual data points observed for the subsystem in question.

For any particular subsystem, the characteristic curve is interrogated by computing the total figure-of-merit and then entering the curve at the figure-of-merit, and reading the corresponding learning curve slope value (as is illustrated in the Fig. 3 curve, $Q_F = 6.5$ and the slope is 84 percent).

This relationship will be approximately as illustrated by Figure 4.

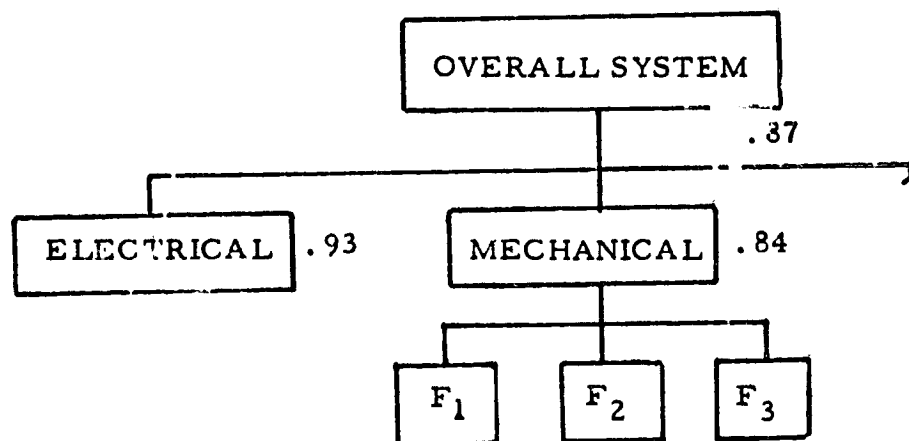


Figure 4. Sample diagram.

The methodology to combine the values for the overall learning/complexity values, as previously obtained, for the various subsystems will be outlined in the following section.

Figure 4 illustrates the relationship of the figure-of-merit analysis to the overall system. The example given for the mechanical system would be handled in the same fashion for other subsystems which make up the overall system.

COMPOSITE COMPLEXITY ANALYSIS

Starting with the determination of learning curves for the various design-oriented factors, the procedure for the final or overall complexity analysis has been outlined in a step-by-step sequence as follows:

- a. Plot learning curves for each of the design-oriented parameters (subsystem in question).
- b. Plot the trend curves for each of the parameters.
- c. By a figure-of-merit analysis of these factors/parameters, determine a representative value for the specific subsystem.
- d. Combine the values of the representative values for each subsystem to yield an overall composite learning curve slope for the total system.

The procedure for accomplishing step d is summarized in Figure 5:

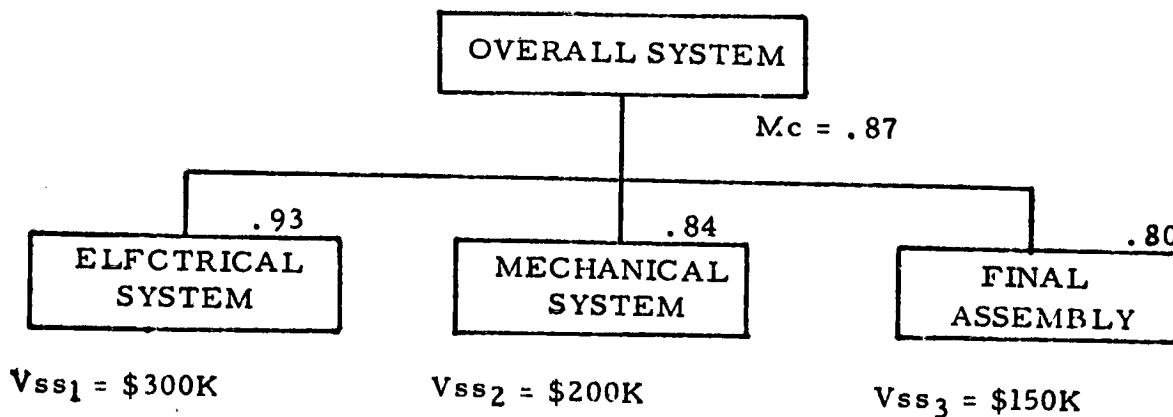


Figure 5. Sample.

$$M_c = \sum [V_{ss}/T] M_{ss} \text{ and } \dots$$

$$M_p = [V_{s3}/T] M_{ss} \text{ ,}$$

where

M_c = Slope of the overall learning curve. _____

M_p = Proportionate value of the overall learning curve slope, attributed to a particular subsystem.

V_{ss} = Value in dollars or manhours for a particular subsystem or program element.

T = Total cost in dollars or manhours of the overall system.

M_{ss} = Learning curve value for the subsystem or program element.

To illustrate the computational procedure for the final learning curve slope or system manufacturing complexity, the sample problem as previously shown will be used.

Given: $V_{ss_1} = \$ 300K$, $V_{ss_2} = \$ 200K$, $V_{ss_3} = \$ 150K$, $M_{ss_1} = 93\%$,

$M_{ss_2} = 84\%$, $M_{ss_3} = 80\%$.

$$M_c = \sum [V_{ss}/T] M_{ss}$$

$$M_c = (300/650) 93 + (200/650) 84 + (150/650) 80$$

$$= .461(93) + .3077(84) + .2307(80)$$

$$= 42.873 + 25.847 + 18.46$$

$$M_c = 87.18\% \text{ or } 87\%$$

As can be seen, each subsystem is weighted in accord with the dollar value of the particular subsystem. The manufacturing complexity for the whole system is approximately 87 percent. This means the cost of the second production unit in a sequence will be .87 X cost of the first unit, etc.

COMPUTATION OF THE VALUE IN DOLLARS OR MANHOURS FOR THE OVERALL SYSTEM

As previously indicated, the overall value for the manufacturing complexity is 87 percent. To compute the overall system unit cost for a specific number of production units the following illustrative example is shown:

Given: $M_c = 87\%$, First Unit Cost = \$ 500, or A.

To Find: Value of unit number 60, or Y.

Solution: $M_c = 87\%$, So $-b = .20679$ (from table).

$$Y = A \cdot X^{-b} \text{ (General Form)}$$

$$\text{Log}_{10} Y = \text{Log}_{10} A - b \text{Log}_{10} X$$

$$\text{Log } Y = 2.69897 - (.20679) (1.77815)$$

$$\text{Log } Y = 2.69897 - .3677036$$

$$\text{Log } Y = 2.3312664$$

$$Y_{60} = 214.4204 \text{ or } \$ 214.42 \text{ per unit.}$$

DISCUSSION

The procedural methodology has been outlined throughout this document to compute the manufacturing complexity for a typical system. Illustrative examples have been given to show the various steps which must be taken to calculate the manufacturing complexity for the overall system.

Although complexity factors have in the past been quoted as being increasing functions, i. e., the factor has in general been given as 1.2 or 1.5 times some other number, it must be remembered that in a production sequence the cost of the first unit of production will always represent the maximum cost

of the series. All subsequent cost values will usually represent a savings or cost reduction. This is with the assumption that an element of learning or production improvement is present. If there is none, the slope of the overall learning curve (or manufacturing complexity) would be 100 percent. There will be no decrement in the cost of the first unit in the cost of subsequent units for a production sequence.

Also there is no consideration in this document of those elements of cost which are not directly related to manufacturing. Such cost elements as the safety allowance, realization factor, and personal allowance are examples of cost elements that have not been included; however, they do not directly involve the techniques of manufacturing. The final production cost must include these cost elements to arrive at a final production cost for the overall system.

There will usually be a universe of learning curve values for each design configuration type (DCT), and many of the lower level subsystems will, no doubt, exhibit similar slopes.

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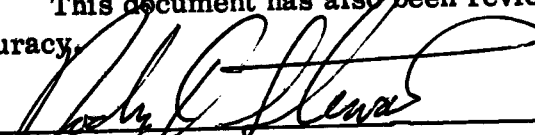
APPROVAL

MANUFACTURING COMPLEXITY ANALYSIS

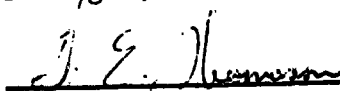
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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSEC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.



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