

AD P 001229



DESIGN TO COST UNDER CHANGING PROGRAM CONDITIONS

"NOTHING IS PERMANENT BUT CHANGE"

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Introduction

The complex process of fielding a new defense system is characterized by a number of factors which frequently cause changes to the originally conceived plans. Changes in the military threat to be addressed, priorities, available resources, allocation of these resources, and a host of other considerations provide a dynamic rather than a static environment for the development, production and fielding of a new system. Despite our efforts to stabilize programs, this dynamic environment is manifested in changes to program quantities and rates of production for a system during its development and production phases.

Department of Defense Directive 5000.28,<sup>(1)</sup> titled "Design to Cost" requires that Design to Cost (DTC) goals be submitted as part of the normal program review milestones, and that these goals be supported by applicable rationale such as quantities, production rates, and cost/quantity relationships. Given the dynamic nature of the programs, the question arises as to what effect the program changes have on the DTC goals. This paper proposes a method for adjusting DTC goals under conditions of changing program quantities and/or anticipated production rates.

The DoD Product Engineering Services Office (DPESO) has developed a cost model<sup>(2)</sup> which relates unit cost to cumulative quantity produced and production rate per year. These three variables are depicted as a three dimensional response surface. The model provides planning information of sufficient accuracy to assist in estimating the effects of various production rate profiles, and would appear to have application in the design to cost arena.

The Rate/Cost/Quantity Model

Traditionally, system costs have been projected using the familiar experience curve. This method depicts the projected unit cost as a function of cumulative quantity produced, without regard for the production rates involved. The rate/cost/quantity model discussed here adds production rate as the "Z" axis of a three-dimensional response surface (Figure 1).

Data inputs for this model consist of historical rate/cost/quantity data for ongoing programs or cost estimates for new programs. Only recurring hardware costs are considered, not total program costs. A multiple regression is performed in which unit cost is the dependent variable and cumulative quantity and production rate are the independent variables. By this method, an equation is derived which describes the three-dimensional response surface relating these variables. Most of the sets of historical data analyzed in this manner to date have shown a high multiple correlation coefficient (in excess of 0.9).

Figure 2 depicts the response surface for a hypothetical weapon system and will serve to compare the experience curve method with the rate/cost/quantity method.

Given:

- First unit cost = \$1000 for a rate of 600 units/year
- 90 percent experience curve slope (exponent  $-.152$ )
- 85 percent rate/cost curve slope (exponent  $-.235$ )
- 6000 units to be produced

Experience curve method:

$$(1) \quad \underline{\text{Unit Cost} = AX^{-B} = 1000 X^{-.152}}$$

Rate/cost/quantity method:

$$\text{Unit Cost} = (A) \text{Quantity}^{-B} \text{Rate}^{-C}$$

Using first unit cost data point to solve for A:

$$1000 = (A) 1^{-.152} 600^{-.235}$$

$$A = 4482$$

Therefore:

$$(2) \quad \underline{\text{Unit Cost} = 4482 Q^{-.152} R^{-.235}}$$

When equation (1) and equation (2) are used to project unit costs versus cumulative quantity at a constant production rate of 600 per year, the results are identical. When equation (1) and (2) are used to predict unit costs for a variable production rate the results are shown in figure 3. As can be seen from this figure, the lower unit costs are associated with the higher production rates, and the higher unit costs are associated with the lower production rates.

Expanding on this concept establishes the following relationships:

$$\underline{\text{IF:}} \quad \text{Unit Cost} = A Q^{-B} R^{-C}$$

- Where:
- A = The intercept of the response surface with the unit cost axis
  - Q = Cumulative quantity produced
  - B = The quantity/cost (experience curve) exponent
  - R = Production rate/year
  - C = Rate/cost exponent

THEN: Cumulative average unit cost =  $\frac{A}{-B+1} Q^{-B} R^{-C}$

AND: Cumulative cost =  $\frac{A}{-B+1} Q^{-B+1} R^{-C}$

(Note: The expression for cumulative average unit cost is an approximation. Significant errors may be introduced if this expression is used for quantities less than approximately 30 units.)

Application of the Model to Design to Cost Goal Adjustments

From the rate/cost/quantity relationships shown above, unit cost, cumulative average unit cost, or cumulative cost could be used in adjusting design to cost goals as program quantities and/or rates are changed. In the following example unit costs are used to illustrate the proposed method.

Assume: Unit cost (\$K) =  $500 Q^{-.1848} R^{-.1135}$

If values for unit cost are held constant, and the equation is solved for corresponding values of cumulative quantity and production rate, the results may be depicted as shown in figure 4.

Figure 4 serves as a framework for illustrating the proposed method for adjusting design to cost goals under changing program conditions. Assume the following sets of conditions for quantities and rates:

	<u>Quantity</u>	<u>Rate/Year</u>	<u>DTC Goal (\$K)</u>
Original plan	600	180	85.03
Change #1	500	100	
Change #2	1000	200	

Using the equation for unit cost, new DTC goals may be calculated, and plotted as shown in figure 5. The results are as follows:

Change #1 New Unit Cost =  $500 (500)^{-.1848} (100)^{-.1135} = \underline{\$94.01K}$

Change #2 New Unit Cost =  $500 (1000)^{-.1848} (200)^{-.1135} = \underline{\$76.45K}$

The three points shown on figure 5 may be summarized as follows:

	<u>Quantity</u>	<u>Rate/Year</u>	<u>DTC Goals (\$K)</u>
Point 1	600	180	85.03
Point 2	500	100	94.01
Point 3	1000	200	76.45

In establishing DTC goals, initial production quantities and rates are prescribed, and an experience curve negotiated. If a slope for the rate/cost curve were determined, the rate/cost/quantity model could provide a method for adjusting DTC goals as program conditions varied. Rate/cost relationships could be derived from proposal data at different rate/quantity conditions, or from experience on prior programs.

### Summary

The PESO cost model was designed to estimate the effects of alternative production rate profiles on unit costs and program costs. Computer programs have been developed and are in use for calculating these results and for displaying the results graphically. This model would appear to have application in determining appropriate adjustments to DTC goals as planned program production rates and/or quantities are changed.

References:

1. Department of Defense Directive 5000.28, May 23, 1975, titled "Design to Cost."
2. Bemis, J.C., "A Model for Examining the Cost Implications of production Rate," Concepts, the Journal of Defense Systems Acquisition Management, Vol. 4, No. 2, Spring 1981, pp 84-94.

3-DIMENSIONAL RESPONSE SURFACE

FOR

RATE/COST/QUANTITY RELATIONSHIPS

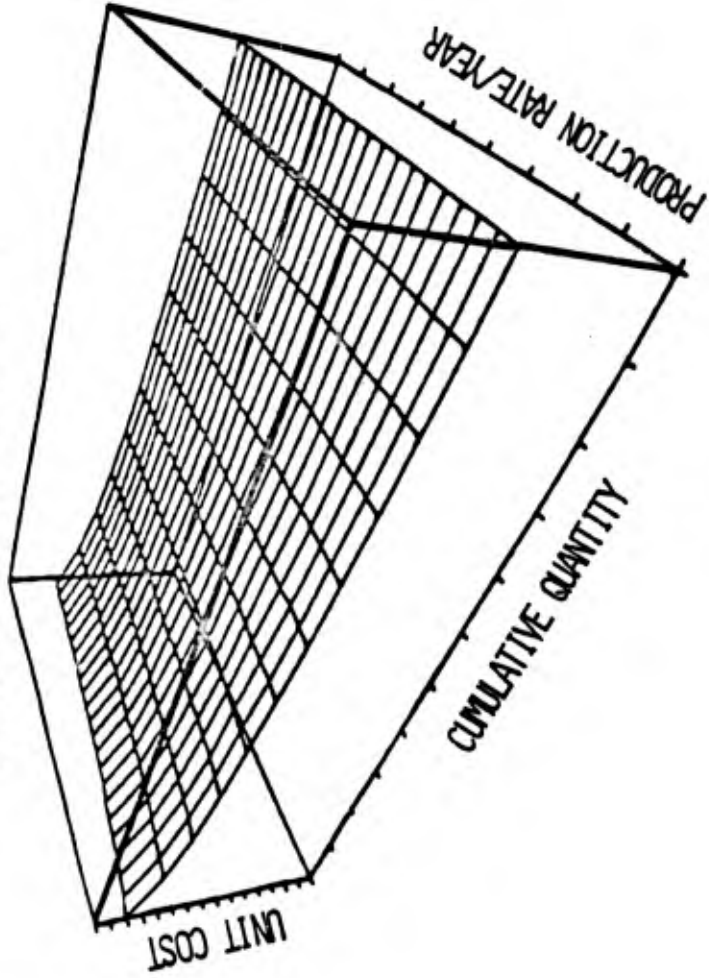
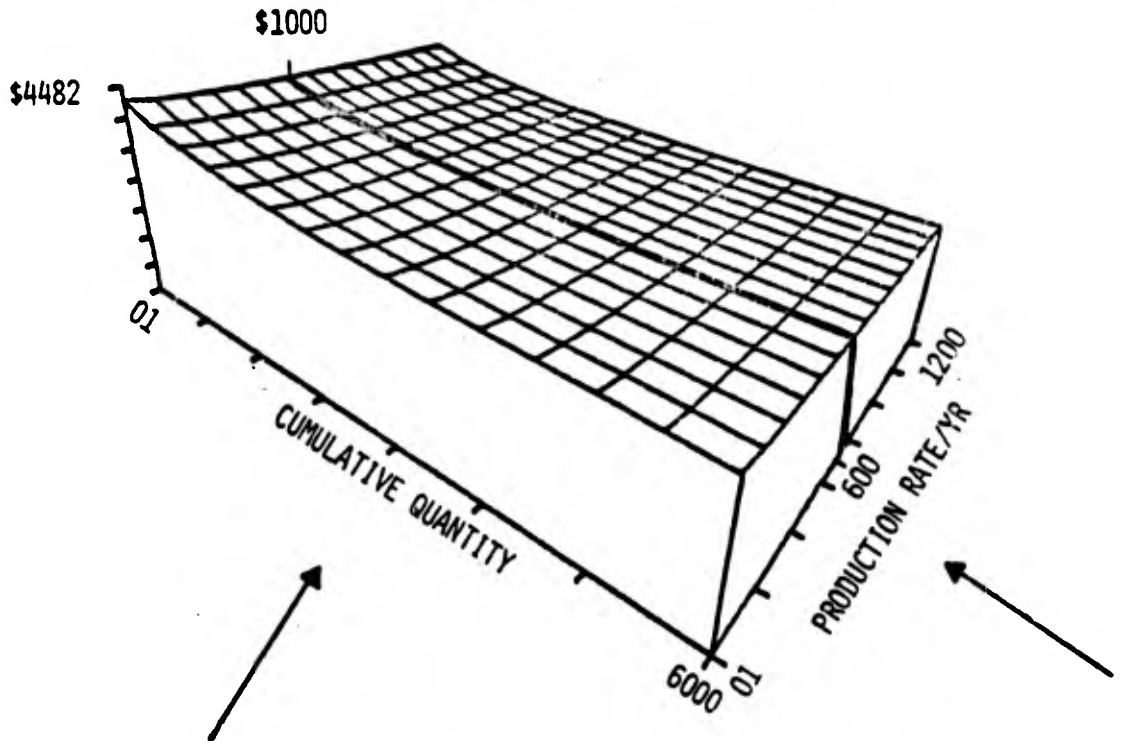


FIGURE 1

COMPARISON BETWEEN CUMULATIVE QUANTITY METHOD  
 AND  
RATE/COST/QUANTITY METHOD  
 (ILLUSTRATION NOT TO SCALE)



GIVEN: FIRST UNIT COST = 1000 FOR RATE OF 600/YR  
 90% LEARNING CURVE SLOPE  
 85% RATE/COST CURVE SLOPE  
 6000 UNITS TO BE PRODUCED

CUM. QUANTITY METHOD:

$$Y = AX^B = 1000 X^{-.152}$$

RATE/COST/QUANTITY METHOD:

$$Y = K Q^{-.XXX} R^{-.XXX}$$

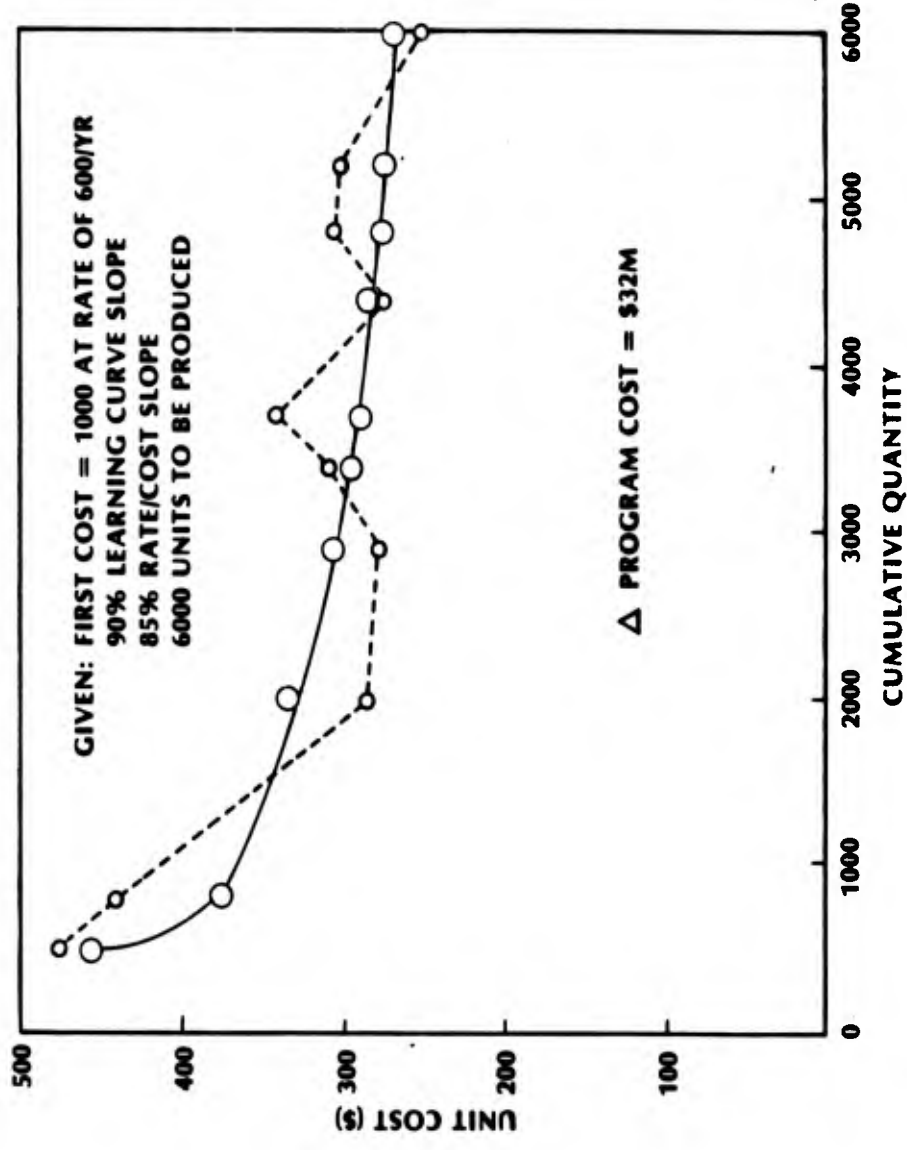
USING FIRST UNIT COST DATA POINT:

$$1000 = K (1)^{-.152} (600)^{-.235}$$

$$K = 4482$$

$$Y = 4482 Q^{-.152} R^{-.2345}$$

FIGURE 2



○ RESULTS FOR Y = 1000 Q<sup>-0.152</sup>

UNIT COST	YEARLY COST	QUANTITY	CUM QTY
457.5525	228776.2	500	500
374.1584	112247.6	300	800
334.3567	401228.3	1200	2000
305.6545	275089.2	900	2900
293.9675	146983.8	500	3400
288.6455	86593.69	300	3700
282.9568	198069.8	700	4400
277.4951	110998.1	400	4800
273.9985	109599.5	400	5200
269.3386	215471.1	800	6000
314.1758	1.885055E + 06	6000	

○ RESULTS FOR Y = 4482 Q<sup>-0.152</sup> R<sup>-0.2345</sup>

UNIT COST	YEARLY COST	QUANTITY	CUM QTY
477.5334	238766.7	500	500
440.1917	132057.5	300	800
284.1904	341028.6	1200	2000
277.9268	250134.1	900	2900
306.8059	153403	500	3400
339.5862	101875.9	300	3700
272.9077	191035.4	700	4400
305.1716	122068.7	400	4800
301.3259	120530.4	400	5200
251.7643	201411.4	800	6000
308.7178	1.852300E + 06	6000	

FIGURE 3

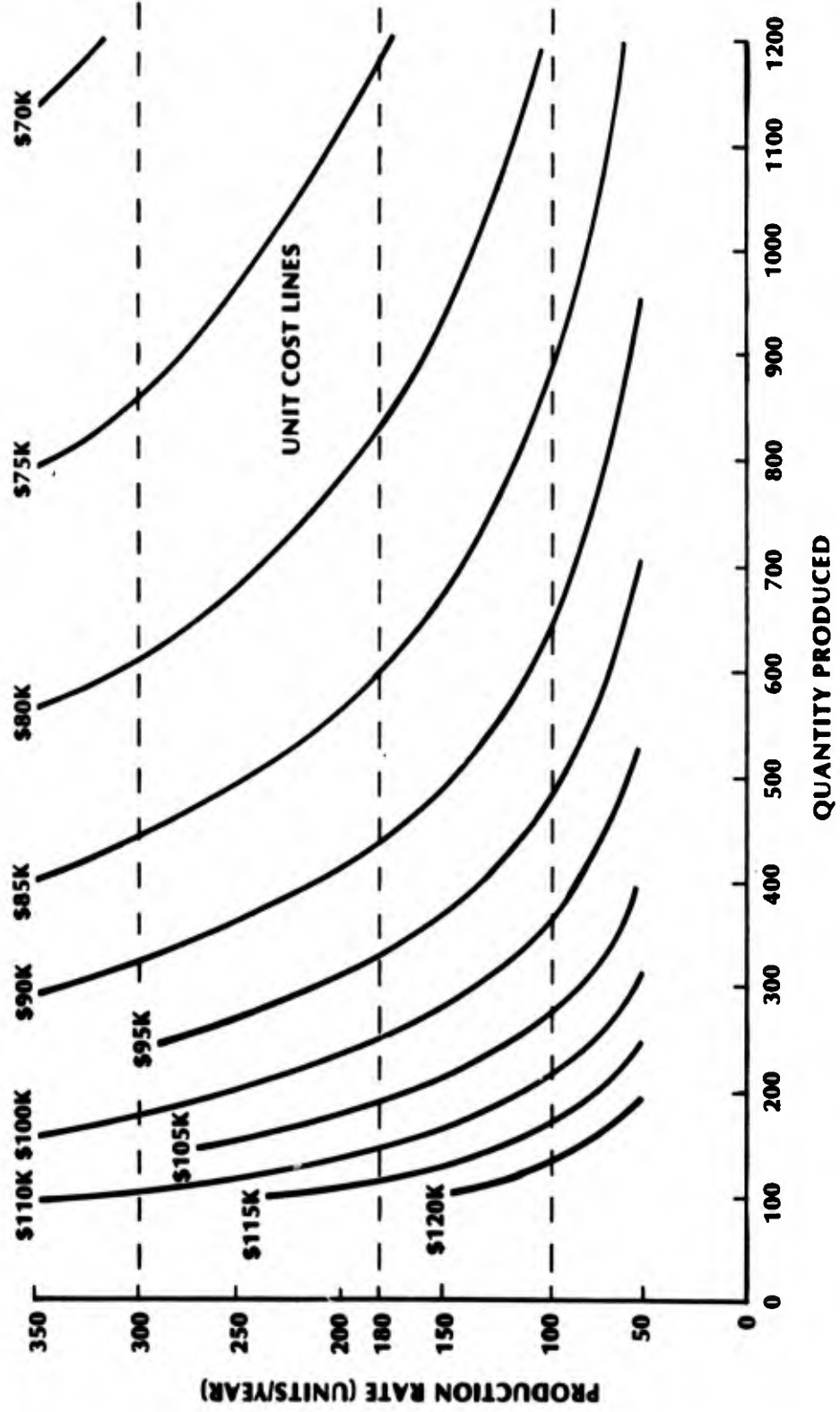


FIGURE 4

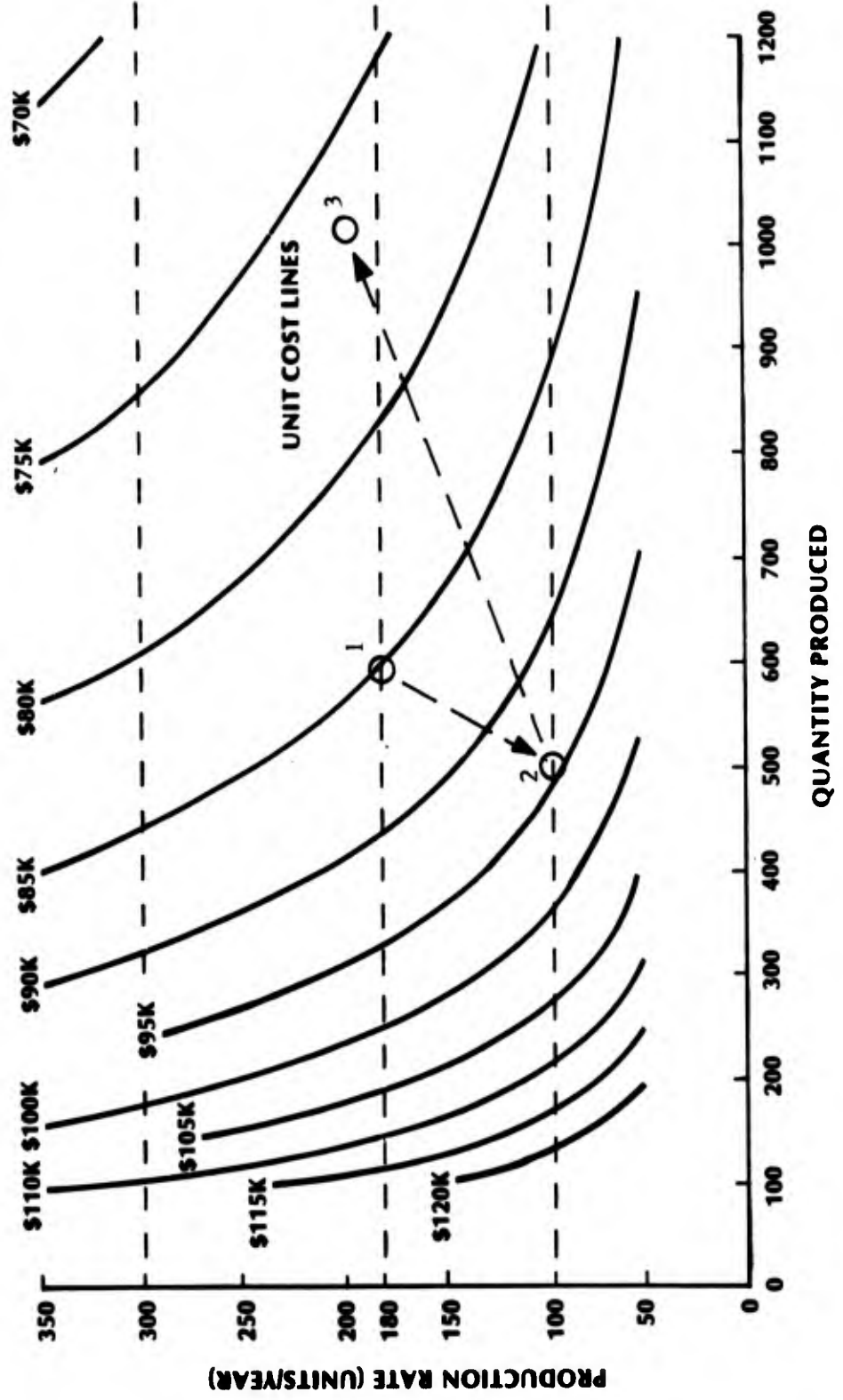


FIGURE 5