RODUCIBILITY ENGINEERING
AND
PLANNING
(PEP)
TECHNICAL REPORT

PREPARED BY

OFFICE OF THE COMPTROLLER
COST ANALYSIS DIVISION
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ABSTRACT

A method of estimating Producibility Engineering and Planning (PEP) costs for proposed armament systems is presented in this report. The method is intended for use in the development phase of the life cycle of an armament system. A cost estimating relationship (CER) has been developed based upon the number of drawings for an armament system. The methodology of CER development as well as historical costs and numbers of drawings are included as an aid to the cost estimator.

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ACKNOWLEDGEMENTS

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- Mr. Donald Wagner, Project Managers Office, Cannon Artillery Weapons System

1. INTRODUCTION

This study was performed by the Cost Analysis Division, Comptroller, US Army Armament Command, and is intended to be used in estimating Producibility Engineering and Planning (PEP) costs for weapon systems which fall within the range of the data points contained herein.

All of the information used in performing this study has been included in the Annex. This information may prove of benefit to the estimator for analogy purposes.

2. PURPOSE

The purpose of this study is to:

a. Present methodology which may be used in estimating the Producibility Engineering and Planning (PEP) costs for proposed armament systems.

b. Record the historical PEP costs and number of drawings of ARMCOM weapons for future analogy and cost estimating purposes.

3. SCOPE OF THE STUDY

The PEP costs included in this study consist of the software portion of advanced production engineering which is funded under the RDT&E appropriation. The activities which comprise the major segments of PEP and a definition of PEP are shown in Section F of the Annex.

This study considered all armament mission items for which historical PEP cost data could be found. These systems include single and multiple barrel guns, automatic guns, grenade launchers, mortars, and towed howitzers.

4. STUDY RESULTS

The derivation of PEP costs based upon the number of estimated drawings for a proposed system has proven to be the best methodology from the cost estimating relationships attempted. The number of drawings can be derived from an engineering estimate or by analogy with similar systems.

a. PEP CER

The PEP Cost Estimating Relationship (CER) analyses were performed on the ARMCOM Cost Analysis Division Wang computer. A screening program of twelve different equation forms was run for each of the four separate independent variables. The equation which proved to be statistically best has been used.

The following PEP CER equation and table of coefficient values (Table 1) can be used in developing PEP costs. The table of coefficient values is provided for equation solution. The estimator must supply the number of drawings for the weapon system being estimated. 1/ The order of useage for the CER is in numeric sequence by order or preference. Number 1 is statistically the most reliable and number 4 is the least reliable (although acceptable).

PEP Cost Estimating Relationship

$$Y = A + B(\mathrm{Ln}X)$$

where: Y = PEP Cost
A = Regression Coefficient
B = Regression Coefficient
X = Number of Drawings

Table 1

Table of Coefficient Values

Independent Variable Number of Drawings	Coefficient A	Coefficient B
1. D-Sized Equivalent Product + Gage	-4642.54599	1105.03876
2. Product + Gage	-5126.74359	1097.34230
3. D-Sized Equivalent Product	-3335.70690	1026.40919
4. Product	-3523.72286	956.70507

1/ The $\log_e$ value (Ln) of the number of drawings (X) is used in the equiation.

b. Statistical Evaluation

The basic form of regression analysis used in developing these CER's is Y = A + BX. Twelve separate variations of this equation were applied as shown in Section A of the Annex. Of the twelve, application of the log form of X proved to be the best statistically in all cases. This form is a curvalinear relationship.

Four independent variables were attempted on the twelve variations of the equation. The coefficient of variation, coefficient of determination, mean of absolute percent deviation, and confidence established by F Test, were used as the basis for determining the best form as well as for rating the independent variables. These statistical measures of credibility were defined in Section G of the Annex.

Results of the statistical evaluation of the best fit form are included in Table 2.

Table 2

Statistical Evaluation

Independent Variable	CER Rating	No. of Data Points	Coefficient Determination	Variation	Mean Absolute Percent Deviation	F Test Confidence
No. of Drawings per weapon system:						
1. D-Sized Equivalent Product + Gage	Good	13	.860	.246	38%	99%
2. Product + Gage	Good	13	.855	.250	24%	99%
3. D-Sized Equivalent Product	Good	13	.845	.259	34%	99%
4. Product	Good	13	.785	.305	32%	99%

5. USE OF THE PEP CER BY THE ESTIMATOR

Basing PEP costs on the number of drawings is considered to be a practical approach to an estimating requirement of a weapon system. Inasmuch as the PEP costs are incurred during the Engineering Design (ED) phase of the system life cycle, an estimating tool capable of early definition is mandatory. The use of numbers of drawings for early definition meets this requirement.

Two techniques for estimating the number of drawings are possible.

The first is to obtain an engineering estimate of the number of drawings. In the case of production drawings, specific numbers are not known in Advanced Development (AD) phase of a system life cycle. However, R&D drawings are required for the production of the AD prototypes. It has been found that there is approximately a 1 to 1 relationship of the R&D drawings to product drawings. This has proven to be a reasonably consistent relationship. An example can be illustrated on the XM198 155mm Towed Howitzer where the product drawings amounted to 95 percent of the R&D drawings. The lesser number of production drawings on the XM198 was a result of standardization and value engineering.

If the above engineering approach cannot be used, another method is available for estimating the number of product drawings. The second method is to make an analogy with a similar system. Also, analogy will normally have to be used to obtain the number of acceptance inspection gage drawings. The number of drawings for several ARMCOM weapon systems is included in Section C of Annex I.

6. COST INFORMATION USED

The cost information used in developing the cost estimating relationships was obtained from two sources.

One was the Production Engineering Measure Project close out reports. Summaries of these reports have been included in Section B of the Annex. The summary, in most cases, contains a detailed breakout of the software types of cost versus purchased equipment, manufacturing labor, and material. This summary was used for differentiating between PEP and IPF costs.

Another source of cost information was the US Army Armament Command and project managers program records. These were used primarily for ongoing programs which have cost visibility of PEP. Summaries of these costs have also been included in Section B of the Annex.

All cost information has been brought up to FY 76 dollars based on the historical cost multipliers contained in Section H of the Annex.

7. INDEPENDENT VARIABLES CONSIDERED AND USED

One of the most significant elements of the PEP activity is the preparation of product and acceptance inspection gage drawings for the technical data package. This element is the function of time spent in product engineering by the engineer and drawing by a draftsman. Other elements of the PEP activity are shown in Section F of Annex I. These other elements are of minor significance in the overall PEP activity.

Because the largest segment of PEP is related to product engineering and drafting, the number of drawings, which is the output of this effort, is believed to be a logical cost driver.

Several other independent variables were also considered in an unpublished WECOM study conducted in November of 1972. These included weight, R&D cost, investment non-recurring cost, and cost of tooling. Of the independent variables considered at that time, the number of product drawings and a factored D-sized equivalent number of product drawings proved to be the most viable independent variables of those attempted. The D-sized equivalent drawing was developed to provide a common basis for quantifying the number of drawings per weapon system.

In the earlier study, using D-sized equivalent drawings proved to be predictive of PEP costs when commodities were individually grouped, while a composite of all the commodities did not yield results which were as statistically sound. A single relationship was desired which would be predictive for PEP costs of all commodities. As stated earlier in this report, the largest single effort involved in PEP is the product engineering and drafting. Discussion with engineering personnel revealed that a large amount of effort is also involved in the design and drafting of acceptance inspection gages. Therefore, the number of acceptance inspection gage drawings was obtained for systems for which there was both valid cost data and numbers of product drawings. The sum of the number of gage drawings and product drawings was then used as single independent variable which was found to be predictive of PEP costs for all commodities.

8. SUMMARY OF PEP COST AND DRAWING INFORMATION USED

Table 3 contains a summary of the PEP costs and numbers of drawings used in the study. Dollar amounts are expressed in the year of mid-point of expenditure as well as in FY 76 dollars.

TABLE 3

COST - DRAWING SUMMARY

Weapon System	Preparing Activity 1/	FY	PEP COSTS $000 Cost 2/	PEP COSTS $000 FY 76 $	NUMBER OF DRAWINGS Actual Product	Actual Gage	D-Sized Equivalent Product	D-Sized Equivalent Gage
Gren Launcher, 40mm, M203	C	69	$ 197	$ 297	72	91	60	89
Gren Launcher, 40mm, XM129	C	66	$ 490	$ 862	142	206	111	180
Auto Gun, 7.62mm, M134	C	65	488	888	103	241	63	180
Auto Gun, 20mm, M61A1	C	50	965	2,895	287	674	168	488
Auto Gun, 20mm, M39A3	IH	65	1,158	2,165	208	247	140	134
Auto Gun, 20mm, M139	IH	66	1,016	1,778	295	256	144	118
Auto Gun 30mm, XM140	C	68	1,863	2,981	271	327	237	330
Light Weight Company Mortar*	IH	75	$ 941(e)	$ 988(e)	157	104	91	69
Mortar, 4.2mm, M30*	IH	65	519	971	233	129	81	72
Mortar, 81mm, M29A1*	IH	65	529	989	164	137	54	61
*Excludes fire control								
Towed Howitzer, 105mm, M102	IH	60	$1,469	$3,144	1,750	1,243	874	747
Towed Howitzer, 105mm, XM204	IH	75	3,363(e)	3,531(e)	2,040(e)	1,446(e)	1,059(e)	991(e)
Towed Howitzer, 155mm, XM198	IH	75	3,899	4,094	2,377	1,432	1,281	977
Includes fire control								

1/ C = Contractor
IH = In-House (Government)

2/ Software Costs of APE

9. <u>REFERENCES</u>

a. AR 70-1, "Army Research, Development, and Acquisition", 1 June 1975.

b. DA PAM 11-2, R&D Cost Guide for Army Materiel System, May 1976.

c. Cesare Raimondi, "Estimating Drafting Time - Art, Science, Guesswork", Machine Design, 7 September 1972.

d. Current Wage Developments, September 1971, #284 Table 1, US Department of Labor, Bureau of Labor Statistics.

e. National Survey of Professional, Administrative, Technical and Clerical Pay, 1975, Bureau of Labor Statistics.

f. William A. Spurr, Lester S. Kellogg, and John H. Smith, <u>Business and Economic Statistics</u>, Richard D. Irwin, INC., Homewood, Illinois, 1964 revised edition.

g. Department of Army, US Army Armament Command, Comptroller, Cost Analysis Division, Cost Analysis Workshop Course Book, "Standard Regression Theory".

ANNEX

PRODUCIBILITY ENGINEERING AND PLANNING

ANNEX

A. Regression Analyses Results

B. Cost Data

   1. Summary Cost Data

   2. System Cost Histories

C. Number of Drawings

D. D-Sized Equivalent Drawing Methodology

E. Ratio of Engineering Man-hours to Drafting Man-hours

F. PEP Activities and Definition

G. Measures of Statistical Credibility

H. Historical Cost Multipliers

SECTION A

Regression Analysis Results

This section of the annex contains the results of applying twelve forms of regression to the historical data on 13 weapon systems.

Four independent variables have been regressed against the PEP cost of each system.

The results of these regression analyses are suitable for predicting the PEP costs of a weapons system. The estimator must provide the number of drawings for the weapon system on which PEP costs are being estimated.

The four analyses are as follows:

- I D-Sized Equivalent Product plus Acceptance Inspection Gage Drawings
- II Product Drawings plus Acceptance Inspection Gage Drawings
- III D-Sized Equivalent Product Drawings
- IV Product Drawings

The following data was used in performing the regression analyses.

WEAPON SYSTEM	DEPENDENT VARIABLE	INDPENDENT VARIABLES USED			
	PEP Cost FY 76 $ (000)	Number of Drawings			
		Product		Product + Gage	
		Actual	D-Sized Equivalent	Actual	D-Sized Equivalent
M203 40mm Gren Launcher	$ 297	72	60	163	149
XM129 40mm Gren Launcher	$ 862	142	111	348	291
M134 Auto Gun 7.62mm	888	103	63	344	243
M61A1 Auto Gun 20mm	2,895	287	168	961	656
M39A3 Auto Gun 20mm	2,165	208	140	455	274
M139 Auto Gun 20mm	1,778	295	144	551	262
XM140 Auto Gun 30mm	2,981	271	237	598	567
Light Weight Comp Mortar*	$ 988	157	91	261	160
M30 Mortar 4.2"*	971	233	81	362	153
M29A1 Mortar 81mm*	989	164	54	301	115
M102 Towed How 105mm	$3,144	1,750	874	2,993	1,621
XM204 Towed How 105mm (e)	3,531(e)	2,040(e)	1,059(e)	3,486(e)	2,050(e)
XM198 Towed How 155mm	4,094	2,377	1,281	3,809	2,258

* - Excludes fire control.

e - Estimated.

REGRESSION ANALYSIS - TWO VARIABLES

SCREENING PROGRAM

D-SIZED EQUIVALENT PRODUCT + ACCEPTANCE INSPECTION GAGE DRAWINGS

X = NUMBER OF D-SIZED EQUIVALENT PRODUCT + ACCEPTANCE INSPECTION GAGE DRAWINGS

Y = PEP COST IN FY 76 $(000)

INPUT DATA

X VALUE	Y VALUE
149.0000	297.0000
291.0000	862.0000
243.0000	888.0000
656.0000	2895.0000
274.0000	2165.0000
262.0000	1778.0000
567.0000	2981.0000
160.0000	988.0000
153.0000	971.0000
115.0000	989.0000
1621.0000	3144.0000
2050.0000	3531.0000
2258.0000	4094.0000

FORM 1 $Y = A+BX$

A = 1029.15692
B = 1.38697

COEFFICIENT OF DETERMINATION : .74192
COEFFICIENT OF VARIATION : .33387

FORM 2 $Y = A+B(LN\ X)$

A = -4642.54599
B = 1105.03876

COEFFICIENT OF DETERMINATION : .85960
COEFFICIENT OF VARIATION : .24626

FORM 3 $LN\ Y = A+BX$

A = 6.86375
B = .00072

COEFFICIENT OF DETERMINATION : .52355
COEFFICIENT OF VARIATION : .07529

FORM 4 $Y = 1/(A+BX)$

A = .00122
B = -.00000

COEFFICIENT OF DETERMINATION : .23611
COEFFICIENT OF VARIATION : .87742

FORM 5 $Y = AX^B$

A = 40.85701
B = .60893

COEFFICIENT OF DETERMINATION : .67867
COEFFICIENT OF VARIATION : .06183

FORM 6 $SQRT\ Y = A+BX$

A = 31.70537
B = .01532

COEFFICIENT OF DETERMINATION : .64954
COEFFICIENT OF VARIATION : .21487

FORM 7 $Y = A+B(\text{SQRT } X)$

A = 32.25717
B = 85.06506

COEFFICIENT OF DETERMINATION : .81309
COEFFICIENT OF VARIATION : .28413

FORM 8 $\text{SQRT } Y = A+B(\text{SQRT } X)$

A = 20.41956
B = .95179

COEFFICIENT OF DETERMINATION : .73001
COEFFICIENT OF VARIATION : .18860

FORM 9 $Y^2 = A+BX$

A = 864717.84394
B = 6535.40163

COEFFICIENT OF DETERMINATION : .85218
COEFFICIENT OF VARIATION : .41342

FORM 10 $Y^2 = A+BX^2$

A = 2576358.71353
B = 2.70093

COEFFICIENT OF DETERMINATION : .77457
COEFFICIENT OF VARIATION : .51054

FORM 11 $Y = A+BX+CX^2$

A = 426.15365
B = 3.95874
C = -.00113

COEFFICIENT OF MULTIPLE DETERMINATION : .82633
COEFFICIENT OF PARTIAL DETERMINATION ON X : .52712
COEFFICIENT OF PARTIAL DETERMINATION ON X^2: .32706
COEFFICIENT OF VARIATION : .28725

FORM 12 $Y = A+BX+CX^2+DX^3$

A = -340.51067
B = 8.60025
C = -.00656
D = .00000

COEFFICIENT OF MULTIPLE DETERMINATION : .89923
COEFFICIENT OF VARIATION : .23064

DETAIL ANALYSIS - TWO VARIABLES

D-SIZED EQUIVALENT PRODUCT + ACCEPTANCE INSPECTION GAGE DRAWINGS

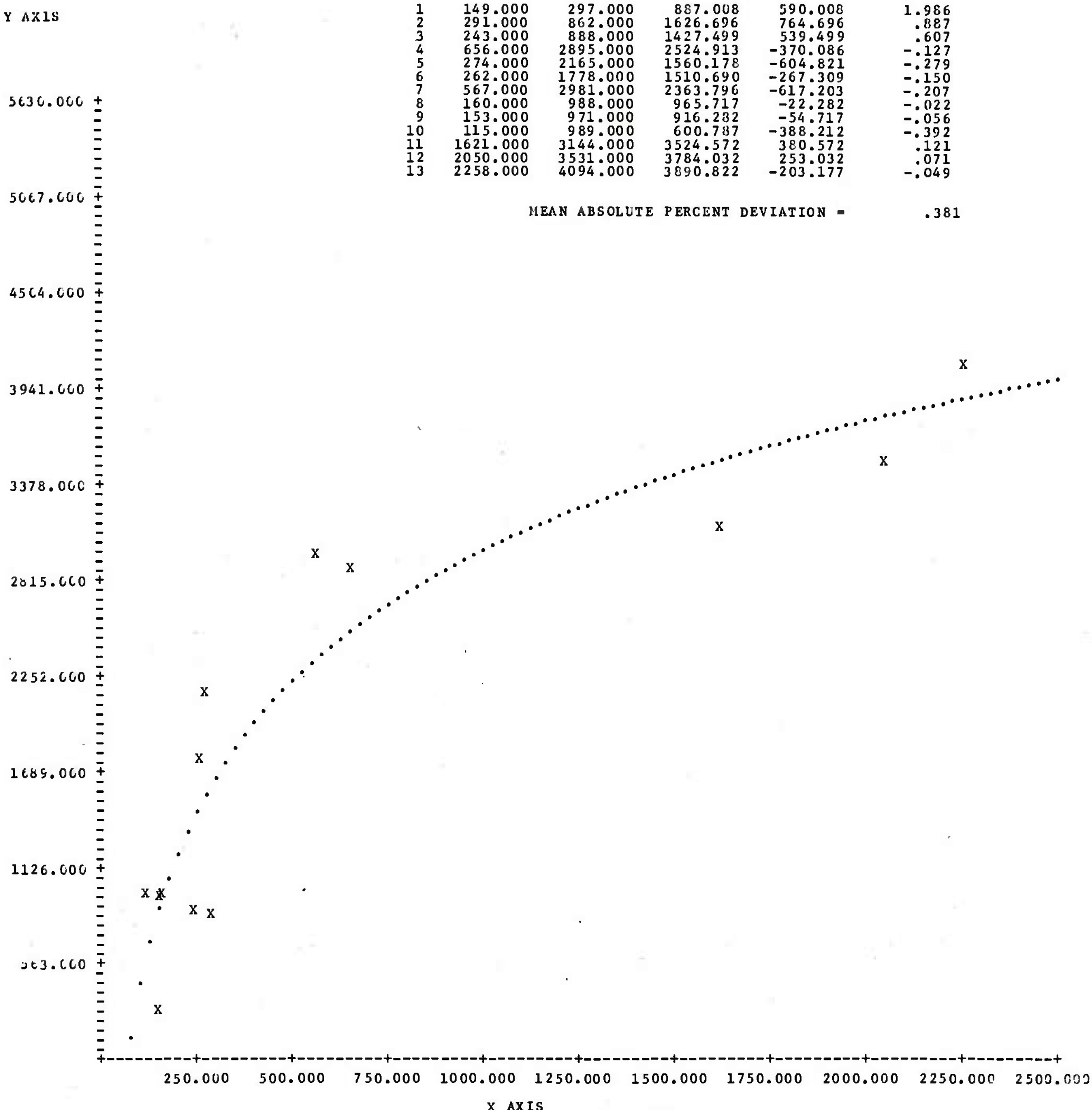
A = -4642.54599

B = 1105.03876

FORM 2

N	X	Y	Y'	dY	% DEV
1	149.000	297.000	887.008	590.008	1.986
2	291.000	862.000	1626.696	764.696	.887
3	243.000	888.000	1427.499	539.499	.607
4	656.000	2895.000	2524.913	-370.086	-.127
5	274.000	2165.000	1560.178	-604.821	-.279
6	262.000	1778.000	1510.690	-267.309	-.150
7	567.000	2981.000	2363.796	-617.203	-.207
8	160.000	988.000	965.717	-22.282	-.022
9	153.000	971.000	916.282	-54.717	-.056
10	115.000	989.000	600.787	-388.212	-.392
11	1621.000	3144.000	3524.572	380.572	.121
12	2050.000	3531.000	3784.032	253.032	.071
13	2258.000	4094.000	3890.822	-203.177	-.049

MEAN ABSOLUTE PERCENT DEVIATION = .381



REGRESSION ANALYSIS - TWO VARIABLES

SCREENING PROGRAM

PRODUCT DRAWINGS + ACCEPTANCE INSPECTION GAGE DRAWINGS

X = NUMBER OF PRODUCT DRAWINGS + ACCEPTANCE INSPECTION GAGE DRAWINGS

Y = PEP COST IN FY 76 $(000)

INPUT DATA

X VALUE	Y VALUE
163.0000	297.0000
348.0000	862.0000
344.0000	888.0000
961.0000	2895.0000
455.0000	2165.0000
551.0000	1778.0000
598.0000	2981.0000
261.0000	988.0000
362.0000	971.0000
301.0000	989.0000
2993.0000	3144.0000
3486.0000	3531.0000
3809.0000	4094.0000

FORM 1 Y = A+BX

A = 1098.33274
B = .77259

COEFFICIENT OF DETERMINATION : .69735
COEFFICIENT OF VARIATION : .36156

FORM 2 Y = A+B(LN X)

A = -5126.74359
B = 1097.34230

COEFFICIENT OF DETERMINATION : .85517
COEFFICIENT OF VARIATION : .25011

FORM 3 LN Y = A+BX

A = 6.89633
B = .00040

COEFFICIENT OF DETERMINATION : .49962
COEFFICIENT OF VARIATION : .07716

FORM 4 Y = 1/(A+BX)

A = .00120
B = -.00000

COEFFICIENT OF DETERMINATION : .23401
COEFFICIENT OF VARIATION : .87862

FORM 5 $Y = AX^B$

A = 26.13403
B = .63254

COEFFICIENT OF DETERMINATION : .73879
COEFFICIENT OF VARIATION : .05575

FORM 6 SQRT Y = A+BX

A = 32.44472
B = .00855

COEFFICIENT OF DETERMINATION : .61370
COEFFICIENT OF VARIATION : .22559

FORM 7 $Y = A+B(\text{SQRT } X)$

PRODUCT DRAWINGS + ACCEPTANCE INSPECTION GAGE DRAWINGS

X = NUMBER OF PRODUCT DRAWINGS + ACCEPTANCE INSPECTION GAGE DRAWINGS

Y = PEP COST IN FY 76 $(000)

A = 144.77979
B = 62.66319

COEFFICIENT OF DETERMINATION : .77414
COEFFICIENT OF VARIATION : .31234

FORM 8 $\text{SQRT } Y = A+B(\text{SQRT } X)$

A = 21.53002
B = .70624

COEFFICIENT OF DETERMINATION : .70520
COEFFICIENT OF VARIATION : .19707

FORM 9 $Y^2 = A+BX$

A = 1194321.47429
B = 3637.24383

COEFFICIENT OF DETERMINATION : .79956
COEFFICIENT OF VARIATION : .48141

FORM 10 $Y^2 = A+BX^2$

A = 2660344.71665
B = .89979

COEFFICIENT OF DETERMINATION : .74821
COEFFICIENT OF VARIATION : .53956

FORM 11 $Y = A+BX+CX^2$

A = 343.72455
B = 2.80459
C = -.00052

COEFFICIENT OF MULTIPLE DETERMINATION : .79233
COEFFICIENT OF PARTIAL DETERMINATION ON X : .46076
COEFFICIENT OF PARTIAL DETERMINATION ON X^2: .31383
COEFFICIENT OF VARIATION : .31411

FORM 12 $Y = A+BX+CX^2+DX^3$

A = -806.99696
B = 6.88223
C = -.00329
D = .00000

COEFFICIENT OF MULTIPLE DETERMINATION : .92846
COEFFICIENT OF VARIATION : .19432

DETAIL ANALYSIS - TWO VARIABLES

A = -5126.74359

B = 1097.34230

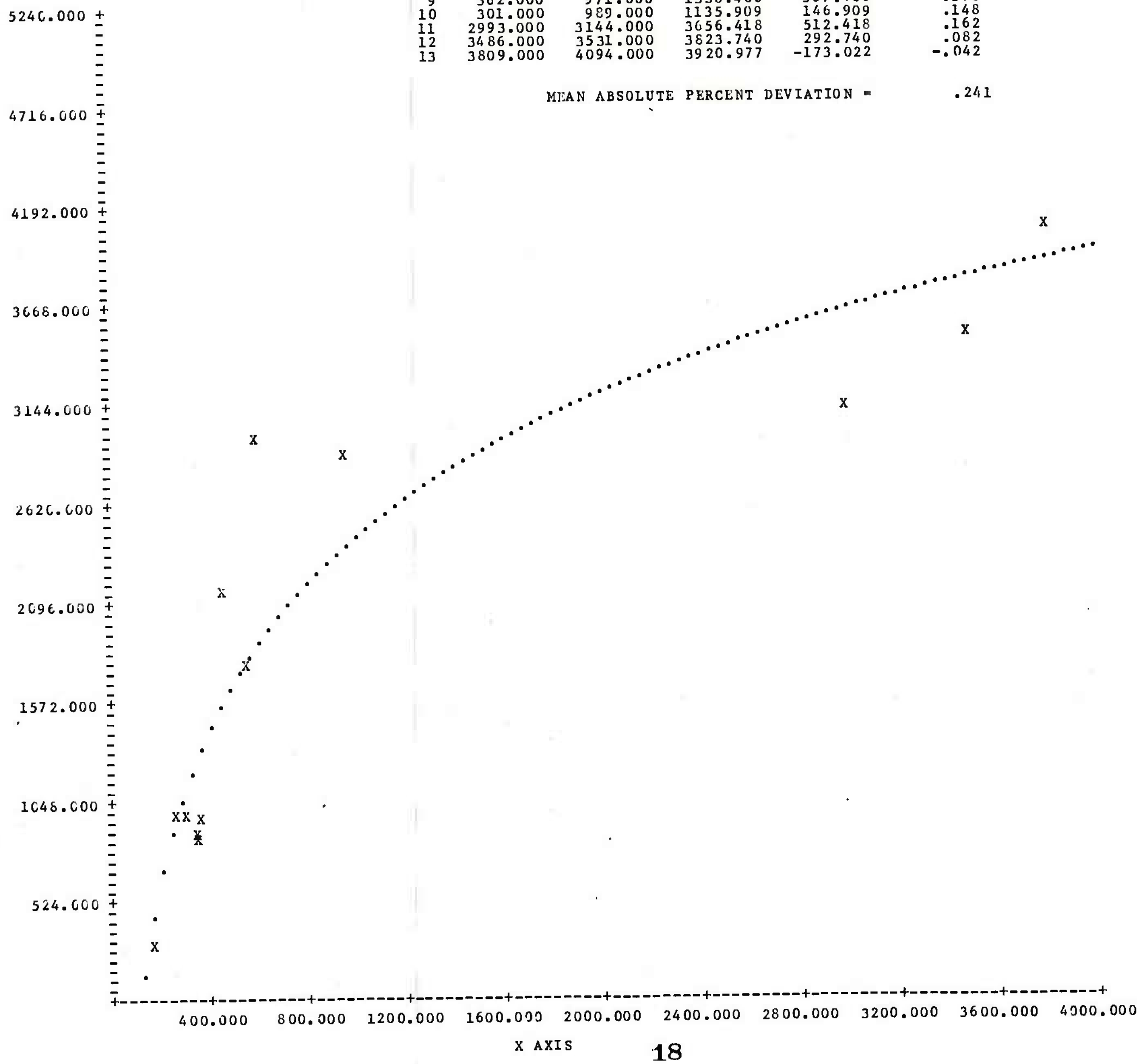
PRODUCT DRAWINGS PLUS ACCEPTANCE INSPECTION
GAGE DRAWINGS

FORM 2

N	X	Y	Y'	dY	% DEV
1	163.000	297.000	462.843	165.843	.558
2	348.000	862.000	1295.125	433.125	.502
3	344.000	888.000	1282.439	394.439	.444
4	961.000	2895.000	2409.775	-485.224	-.167
5	455.000	2165.000	1589.317	-575.682	-.265
6	551.000	1778.000	1799.390	21.390	.012
7	598.000	2981.000	1889.213	-1091.786	-.366
8	261.000	988.000	979.440	-8.559	-.008
9	362.000	971.000	1338.406	367.406	.378
10	301.000	989.000	1135.909	146.909	.148
11	2993.000	3144.000	3656.418	512.418	.162
12	3486.000	3531.000	3823.740	292.740	.082
13	3809.000	4094.000	3920.977	-173.022	-.042

MEAN ABSOLUTE PERCENT DEVIATION = .241

Y AXIS



X AXIS

REGRESSION ANALYSIS - TWO VARIABLES

SCREENING PROGRAM

D-SIZED EQUIVALENT PRODUCT DRAWINGS

X = NUMBER OF D-SIZED EQUIVALENT PRODUCT DRAWINGS

Y = PEP COSTS IN FY 76 $(000)

INPUT DATA

X VALUE	Y VALUE
60.0000	297.0000
111.0000	862.0000
63.0000	888.0000
168.0000	2895.0000
140.0000	2165.0000
144.0000	1778.0000
237.0000	2981.0000
91.0000	988.0000
81.0000	971.0000
54.0000	989.0000
874.0000	3144.0000
1059.0000	3531.0000
1281.0000	4094.0000

FORM 1 Y = A+BX

A = 1169.93299
B = 2.37769

COEFFICIENT OF DETERMINATION : .68341
COEFFICIENT OF VARIATION : .36979

FORM 2 Y = A+B(LN X)

A = -3338.69521
B = 1025.99259

COEFFICIENT OF DETERMINATION : .84502
COEFFICIENT OF VARIATION : .25873

FORM 3 LN Y = A+BX

A = 6.94114
B = .00122

COEFFICIENT OF DETERMINATION : .47289
COEFFICIENT OF VARIATION : .07920

FORM 4 Y = 1/(A+BX)

A = .00116
B = -.00000

COEFFICIENT OF DETERMINATION : .21034
COEFFICIENT OF VARIATION : .89209

FORM 5 $Y = AX^B$

A = 82.05587
B = .56947

COEFFICIENT OF DETERMINATION : .67686
COEFFICIENT OF VARIATION : .06201

FORM 6 SQRT Y = A+BX

A = 33.30713
B = .02613

COEFFICIENT OF DETERMINATION : .59205
COEFFICIENT OF VARIATION : .23183

FORM 7 Y = A+B(SQRT X)

A = 299.11943
B = 107.29626

COEFFICIENT OF DETERMINATION : .76220
COEFFICIENT OF VARIATION : .32049

FORM 8 SQRT Y = A+B(SQRT X)

A = 23.45289
B = 1.19749

COEFFICIENT OF DETERMINATION : .68084
COEFFICIENT OF VARIATION : .20505

FORM 9 $Y^2 = A+BX$

A = 1482698.62355
B = 11338.81478

COEFFICIENT OF DETERMINATION : .80403
COEFFICIENT OF VARIATION : .47602

FORM 10 $Y^2 = A+BX^2$

A = 2813928.65883
B = 8.71995

COEFFICIENT OF DETERMINATION : .74657
COEFFICIENT OF VARIATION : .54132

FORM 11 $Y = A+BX+CX^2$

A = 721.23292
B = 6.61864
C = -.00343

COEFFICIENT OF MULTIPLE DETERMINATION : .74845
COEFFICIENT OF PARTIAL DETERMINATION ON X_2: .37946
COEFFICIENT OF PARTIAL DETERMINATION ON X^2: .20545
COEFFICIENT OF VARIATION : .34571

FORM 12 $Y = A+BX+CX^2+DX^3$

A = -561.26052
B = 21.94228
C = -.03209
D = .00001

COEFFICIENT OF MULTIPLE DETERMINATION : .92159
COEFFICIENT OF VARIATION : .20345

DETAIL ANALYSIS - TWO VARIABLES

A = -3338.69521

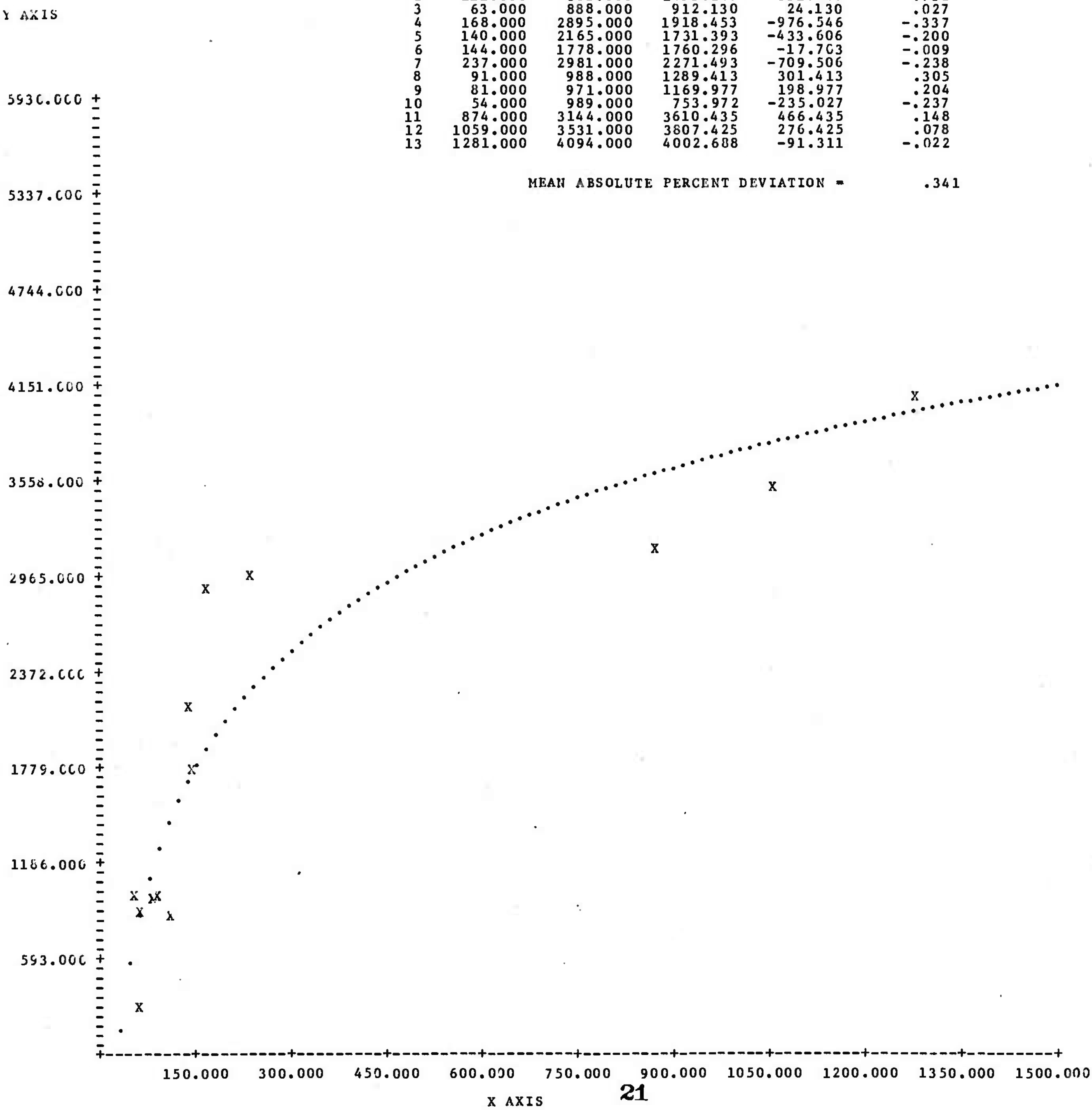
B = 1025.99259

D-SIZED EQUIVALENT PRODUCT DRAWINGS

FORM 2

N	X	Y	Y'	dY	% DEV
1	60.000	297.000	862.071	565.071	1.902
2	111.000	862.000	1493.247	631.247	.732
3	63.000	888.000	912.130	24.130	.027
4	168.000	2895.000	1918.453	-976.546	-.337
5	140.000	2165.000	1731.393	-433.606	-.200
6	144.000	1778.000	1760.296	-17.703	-.009
7	237.000	2981.000	2271.493	-709.506	-.238
8	91.000	988.000	1289.413	301.413	.305
9	81.000	971.000	1169.977	198.977	.204
10	54.000	989.000	753.972	-235.027	-.237
11	874.000	3144.000	3610.435	466.435	.148
12	1059.000	3531.000	3807.425	276.425	.078
13	1281.000	4094.000	4002.688	-91.311	-.022

MEAN ABSOLUTE PERCENT DEVIATION = .341



REGRESSION ANALYSIS - TWO VARIABLES

SCREENING PROGRAM

PRODUCT DRAWINGS

X = NUMBER OF PRODUCT DRAWINGS

Y = PEP COSTS IN FY 76 $(000)

INPUT DATA

X VALUE	Y VALUE
72.0000	297.0000
142.0000	862.0000
103.0000	888.0000
287.0000	2895.0000
208.0000	2165.0000
295.0000	1778.0000
271.0000	2981.0000
157.0000	988.0000
233.0000	971.0000
164.0000	989.0000
1750.0000	3144.0000
2040.0000	3531.0000
2377.0000	4094.0000

FORM 1 Y = A+BX

A = 1221.59892
B = 1.19795

COEFFICIENT OF DETERMINATION : .64391
COEFFICIENT OF VARIATION : .39218

FORM 2 Y = A+B(LN X)

A = -3523.72286
B = 956.70507

COEFFICIENT OF DETERMINATION : .78518
COEFFICIENT OF VARIATION : .30461

FORM 3 LN Y = A+BX

A = 6.96616
B = .00062

COEFFICIENT OF DETERMINATION : .44937
COEFFICIENT OF VARIATION : .08094

FORM 4 Y = 1/(A+BX)

A = .00114
B = -.00000

COEFFICIENT OF DETERMINATION : .20580
COEFFICIENT OF VARIATION : .89466

FORM 5 $Y = AX^B$

A = 66.27249
B = .55034

COEFFICIENT OF DETERMINATION : .67553
COEFFICIENT OF VARIATION : .06213

FORM 6 SQRT Y = A+BX

A = 33.86549
B = .01318

COEFFICIENT OF DETERMINATION : .55913
COEFFICIENT OF VARIATION : .24100

FORM 7 Y = A+B(SQRT X)

A = 432.38174
B = 73.41525

COEFFICIENT OF DETERMINATION : .70645
COEFFICIENT OF VARIATION : .35608

FORM 8 SQRT Y = A+B(SQRT X)

A = 24.87073
B = .82268

COEFFICIENT OF DETERMINATION : .63617
COEFFICIENT OF VARIATION : .21893

FORM 9 Y^2 = A+BX

A = 1727250.12860
B = 5715.77717

COEFFICIENT OF DETERMINATION : .75834
COEFFICIENT OF VARIATION : .52860

FORM 10 Y^2 = $A+BX^2$

A = 2823927.48313
B = 2.40828

COEFFICIENT OF DETERMINATION : .73435
COEFFICIENT OF VARIATION : .55422

FORM 11 Y = $A+BX+CX^2$

A = 857.35136
B = 3.21506
C = -.00087

COEFFICIENT OF MULTIPLE DETERMINATION : .67997
COEFFICIENT OF PARTIAL DETERMINATION ON X_2: .21915
COEFFICIENT OF PARTIAL DETERMINATION ON X^2: .10125
COEFFICIENT OF VARIATION : .38994

FORM 12 Y = $A+BX+CX^2+DX^3$

A = -624.65600
B = 13.06685
C = -.01042
D = .00000

COEFFICIENT OF MULTIPLE DETERMINATION : .85286
COEFFICIENT OF VARIATION : .27871

DETAIL ANALYSIS - TWO VARIABLES

PRODUCT DRAWINGS

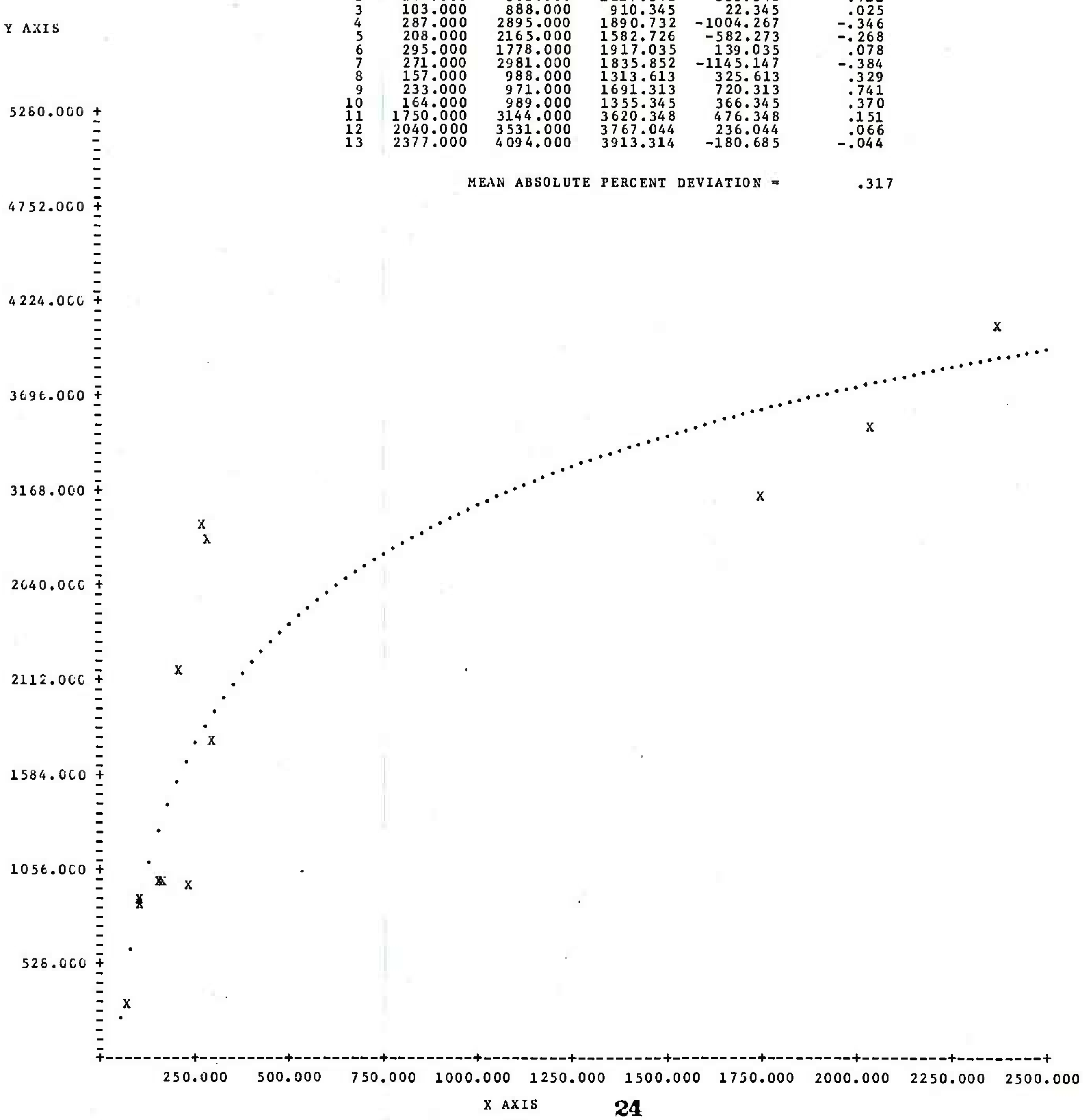
A = -3523.72286

B = 956.70507

N	X	Y	Y'	dY	% DEV
1	72.000	297.000	567.785	270.785	.911
2	142.000	862.000	1217.542	355.542	.412
3	103.000	888.000	910.345	22.345	.025
4	287.000	2895.000	1890.732	-1004.267	-.346
5	208.000	2165.000	1582.726	-582.273	-.268
6	295.000	1778.000	1917.035	139.035	.078
7	271.000	2981.000	1835.852	-1145.147	-.384
8	157.000	988.000	1313.613	325.613	.329
9	233.000	971.000	1691.313	720.313	.741
10	164.000	989.000	1355.345	366.345	.370
11	1750.000	3144.000	3620.348	476.348	.151
12	2040.000	3531.000	3767.044	236.044	.066
13	2377.000	4094.000	3913.314	-180.685	-.044

MEAN ABSOLUTE PERCENT DEVIATION = .317

FORM 2



SECTION B

Cost Data

This section of the annex contains cost history on each weapon system used in the CER. Cost histories are also shown on a few additional systems which were not used in the CER.

COST DATA

A data search of investment non-recurring costs was made on 32 weapon systems for Advanced Production Engineering (APE) costs. Investment non-recurring APE cost data was found on 21 weapon systems. A further breakout of costs was attempted to identify the engineering effort, pilot line set up, prototype production, gage fabrication and tooling. A breakout of this type was possible to varying degrees on 14 systems.

Production Engineering Measure Project Summaries were found on these 14 systems, which yielded visibility of software costs versus purchased equipment and manufacturing labor and material. These summaries have been used as a basis for identifying PEP and IPF costs. Project close out reports were used to identify final cost summaries.

Cost information on systems in R&D have been updated to include sunk costs and an estimate of cost to complete.

In some instances, two cost estimates appear. The reason for showing both is because of a different cost breakout. The order of magnitude is visible in both estimates.

Cost data has been included for some systems not included in the CER's. The reason for including these costs is to provide the estimator with factual cost history for analogy purposes.

PRODUCIBILITY ENGINEERING AND PLANNING (PEP)

SUMMARY COST DATA
($000)

		Program Summary		APE Project Summary			
					PEP		
Weapon System	FY	APE	APE & IPF	Project Number	Tech Data Pack	Other	IPF
Aircraft							
XM18E1 Hel Arm Sub Sys 7.62mm Gun	65	$ 149					
M15 Hel Arm Sub Sys	63			30312	$ 500(e)		
M21 Hel Arm Sub Sys 7.62mm Gun	65	$ 434		10325	$ 434		
M28 Hel Arm Sub Sys 40mm/7.62mm	67		$3,823				
M134 Automatic Gun 7.62mm	65	$ 488		10328	$ 488		
XM129 Grenade Launcher 20mm	66	$ 490		10330/ 6716	$ 370		
XM140 Automatic Gun 30mm	68	$2,143		23049	$1,364	$499 (QASM)	$ 280
M60 Machine Gun 7.62mm	56/57	$ 171					
M61A1 Automatic Gun 20mm	50	$ 965					
Rifle							
M16 Rifle 5.56mm	67/68	$4,500 1/		6867/ 6753	$ 211(e)		$6,152/ 6,295
XM203 Gren Launch Attach 40mm	69	$ 350			$ 110	$ 87 (EQD)	$ 153
Auto Guns							
M39A3 Automatic Gun 20mm	65/68	$1,158		6009/ 4095			
M139 Automatic Gun 20mm	66/68	$1,713		6256	$1,016		$ 691
Air Defense							
XM163/XM167 Vulcan Air Def 20mm		None					
FAADS	66	$ 408(e)		66406	$ 408(e)		

1/ Costs are for the rights to produce the gun.

PRODUCIBILITY ENGINEERING AND PLANNING (PEP)(con't)
SUMMARY COST DATA

Weapon System	FY	Program Summary PEP	Program Summary APE	Program Summary APE & IPF	APE Project Summary Project Number	APE Project Summary PEP Tech Data Pack	APE Project Summary PEP Other	APE Project Summary IPF
Howitzers								
M102 Towed Howitzer 105mm	60		$1,469					
XM204 Towed Howitzer 105mm	74	$3,363			7513	$2,025(e)(ex:fire control)		
XM198 Towed Howitzer 155mm	75	$3,899			FY 73/74	$3,125(e)	$692(e) (EQD)/ $788(e) (TLD)	$ 4,254(e)
SP Vehicles								
M108/M109 SP Howitzer 105mm 155mm	61		$7,516					
M107/M110/ M478 SP Howitzer Gun			$2,186		6725/ 6756			
M551 ARAAV	62/64		$19,332					
Mortar (w/o fire control)								
LWCM Light Weight Company Mortar	75	$942			7492	$895(e)	$254(e) (EQD)/ $571(e) (QASM)	$ 435(e)
M20	65			$737	66237	$489	$144 (PP/PL/EQO/ TD/QA)	$ 105
M30	65			$962	66259	$519		$ 304
Fire Control								
Mortar-LWCM XM64E1 Sight	75	$595						
Howitzers XM198 and XM204	75	$920						

Includes: Panoramic telescope, elevation quadrant, elbow telescope, telescope, colimator, a fuze setter.

(e) Estimated
EQD Equipment Design
TLD Tool Design
QASM QA/Systems Mgmt
PP/PL Production Planning/Plant Layout

Source: Production Base Support
Production Engineering Measures Projects
Project Justification - Exhibit P16

XM203 Grenade Launcher FY 69 APE $349,800

AAI Corporation (TDP prior to quantity production)

Equipment Design	$ 86,800
TDP	110,000
Gage Fabrication	153,000
	$349,800

			Pro Rata Profit Fee	
Material	$ 20,000	6%	$ 672	$ 20,672
Mfg Labor & Burden	103,000	30%	3,360	106,360
Eng Labor & Burden	168,800	50%	5,600	174,400
Monitoring Initial Prod Test, Drafting, Misc	46,800	14%	1,568	48,368
Profit of Fee	$ 11,200			
Total				$349,800

Source: Production Base Support Project Close Out Report

APE Project #10330 FY 66 $489,500

PEP

Technical Data Package (TDP) 369,500

*Additional amount of $120,000 APE was provided with the initial procurement of the hardware system.

Source: Production Base Support Project Close Out Report

APE Project #10328 FY 65	$488,477

PEP Technical Data Package (TDP)

Government In-House	$100,000
Contract	$390,000

Source: Production Base Support
Production Engineering Measure Projects

APE Project #6256 FY 66 $1,707,000

Convert Drawings - US Stds	350,000	PEP
Prepare Production Ordnance Drawings	80,000	PEP
Packaging + Data Sheets	58,000	PEP
Feasibility Translating European TDP	10,000	PEP
Travel	35,000	PEP
Assure US Drwngs Compatible/Guns Match Drwngs	208,000	PEP
Gage Design, QUAPS-SQUAPS, Reliab Stds	275,000	PEP
LLT Final Insp Equip	280,000	IPF
Mfg 4 Prototypes	351,000	IPF
Tooling Gages	60,000	IPF

Material	250,000
Material Burden	168,000
Labor Mfg	224,000
Labor Eng	710,000
Labor Burden	355,000

Eng RD	Process Engring	100,000	PEP
	Engineering & Drawings	340,000	PEP
	Specs & Pkg Data	50,000	PEP
	Travel	35,000	PEP
	Mfg 4 Prototypes (2 tool sets)	354,000	IPF
	10 Offshore Guns	75,000	IPF
	APG Test Program	138,000	PEP
	Other	60,000	PEP
		1,152,000	
QAO	Gage Design	180,000	PEP
	Stds	65,000	PEP
	Cert	56,000	PEP
	Audit	10,000	PEP
	Reliability	20,000	PEP
	Gage Procur	224,000	IPF
		555,000	

Source: Product Base Support
Production Engineering Measure

Projects

APE Project #23049 FY 68 $2,143,000

Contract #DAAF 0368-C-0058 13 Dec 68 Philco-Ford Corp Aeronutronic Division $1,364,000
Prepare Technical Data Package for the XM140 Gun

Target Fee $ 100,000
Target Cost $1,250,000

Contractor Effort TDP

Program Management for XM140 30mm Gun
Product Engineering Studies for XM140 Gun
Preparation of Drawings for XM140 Gun
Preparation of Lists Associated with Product Engineering Drawings for XM140 Gun
Packaging and Packaging Design for XM140 Gun
QUAPS for XM140 Gun
Performance Specs and Purchase Description for XM140 Gun
Reliability Engineering for XM140 Gun
Maintainability Engineering for XM140 Gun
Human Factors Engineering for XM140 Gun
Value Engineering Requirements for XM140 Gun
Maintenance of all Product Packaging, QUAPS, Drawings, and Other Data
Reporting for Progress of Work Performance

Other Costs

	PRON #	ISSUED TO	AMOUNT	FOR	
PEP	11-8 23035	SWERI-QA	$ 92,764	IH QA	
IPF	11-8 23069	PPC	243,390	Contr Guns Philo-Ford	LP (4)
IPF	11-8 23072	RIA	17,085	Contr Guns Ammo Proof	BBLS (9)
IPF	11-8 23075	PPC	20,000	Spare Parts Philco-Ford	LP
PEP	11-8 23082	SWERR-REP	190,632	IH Eng Spt Gun + Links	
PEP	11-8 23099	MS	384	Microfilm	
PEP	11-8 23100	QA	59,528	IH Support	
	11-8 23102	SMM-AR	2,281	SSM-AR Maint Demo & Supply Spt	
	11-8 23103	PPC	38,946	Philo-Ford Maint TDP	
PEP	11-8 23107	PPC	22,733	Contr 71C 0318 QA Pamphlet	
	11-8 23110	WVLT	91,748	Update Docu QA E2--E3 Config	

Source: Watervliet Arsenal Production Engineering Measures Projects

APE Project Number 66237

FY 65
28.41 Man Years

PEP

Procurement Package TDP		$375,800

IPF

Equipment Design	$43,200	
Pilot Production	30,000	
Equipment Requisition	70,000	

Direct Labor	$226,700
Material	2,000
Supplies	5,000
Services (Proofing)	45,000
Inspection Equipment	70,000
Overhead	170,420

PEP

Production Planning 4,710 hrs @ $4.04	$ 19,028
Plant Layout 1,769 hrs @ $3.78	2,313
Quality Control 544 hrs @ $3.51	1,909
Overhead	12,917
	1,678
	2,508

IPF

Tool Design 8,197 hrs @ $3.72	$ 30,493
Overhead	22,478

FY 68

PEP 7 Man Years

Procurement Package	$113,000

IPF		$ 12,000
Equipment Design	$ 7,000	
Equipment Acquisition	$ 5,000	

Source: Watervliet Arsenal Production Engineering Measures Projects

APE Project Number 66259

FY 65 PEP			$519,000
RE		$251,000	
Production Engineering	$100,000		
Drafting	40,000		
Process Engineering Support	37,000		
Brazing Development	5,000		
Metalurgical Analysis	10,000		
Maraging Steel	15,000		
Specification Engineering	4,000		
Packaging Engineering	20,000		
Tech Pubs	10,000		
Maintenance Engineering	10,000		
QA		$218,000	
VA		$ 50,000	
IPF		$165,000	$304,000
Prototype (2)	$ 55,000		
Component Hardware	40,000		
Testing (In-House)	15,000		
Testing (APG)	30,000		
Basecap Cast	15,000		
Aluminum Castings	10,000		
AOD		$139,000	

PEP

LWCM
Light Weight Company Mortar

Source: Production Base Support
Production Engineering Measures Projects
Project Justification - Exhibit P16

Project #6747492 FY 74		$2,144,000 (estimate)
PEP		$1,709,000
Equipment Design	$243,000	
TDP	$895,000	
QA-System Management	$571,000	
IPF		$ 435,000
Equipment Fabrication	$295,000	
Equipment Acquisition	$140,000	

PEP

Source: Revised Cost Study by Watervliet Arsenal dated 21 August 1975

PEP $1,536,000

	All FY 75 $		TOTAL $1,536,300
TOTAL	$914,300	$622,000	
Mortar	$541,500	$400,000	$ 941,500
Fire Control XM64E1 Sight Unit	372,800	200,000	594,800

NOTE: Fire control has not been included in the M29A1 and M30 mortars because the data could not be found at Frankford Arsenal.

PEP

XM204
105mm Howitzer

Source: XM204 Product Managers Office,
Mr. R. Lindholm

FY 75 $ $3,363,004 (estimate)

1 October 1976

	Sunk	Estimate To Complete	Total
TOTAL	$867,004	$1,576,010	$3,363,004
Carriage, Recoil, Integration & Assembly	$443,164	$1,252,000	$1,695,164
Cannon (includes Ammunition @ PTA	423,840	324,000	747,840
Fire Control[1/]	(40,611)	(19,000)	-------
Fire Control[1/] (XM198)			920,000

1/ The same fire control is used on the XM204 105mm Towed Howitzer as on the XM198 155mm Towed Howitzer. Therefore, the XM198 Fire Control PEP costs have been substituted because in the usual PEP program, these costs would be incurred.

Source: Production Base Support
Production Engineering Measures Projects
Project Justification - Exhibit P16

APE Project #6737314 FY 73 $3,627,000 (estimate)

PEP	Govt	Contr
Special Tool Design	$ 495,000	
Accep Inspection Gage Design	$ 293,000	
TDP	$2,128,000	
IPF		
Special Tooling Fabrication	$ 487,000	
Acceptance Inspection Fabrication		$224,000

APE Project #6747314 FY 74 $8,473,000 (estimate)

PEP	
Equipment Design	$ 692,000
TDP	$ 997,000
IPF	
Equipment Fabrication	$3,009,000
Equipment Acquisition	$ 545,000
Other	$3,230,000

Source: DRCPM-CAWS, Baseline II Cost Estimate,
XM198 155mm Towed Howitzer, July 1976

The latest cost estimate for this sytem is:

	Sunk	Estimate To Complete	Total
PEP TOTAL	$3,153,700	$745,100	$3,898,800
Carriage, Recoil, Integration & Assembly	$1,332,900	$491,300	$1,824,200
Cannon	940,800	213,800	1,154,600
Fire Control	880,000	40,000	920,000

XM198

Source: Production Base Support
Project Justification Exhibit P16

APE Project #10325 FY 68 $211,000 (estimate)

PEP

Original Estimate on TDP

$100,000 In-House

$111,000 Out-of-House

Included 139 Product Drawings
250 New Gage Design Drawings

FY 67
Rights to Produce M16 Rifle $ 4,500,000

FY 68
Production Lines for M16 Rifle $12,447,000

Harrington & Richardson $6,152
GMC Hydramatic (Ypsulanti) $6,295

PEP

M15
Helicopter Armament Sub System

Source: Production Base Support
Project Justification
Exhibit P16

Advanced Production Engineering (APE)
Project #30312

$500,000 (estimate)

PEP Technical Data Package (TDP)
$8.00 hour x 62,500 manhours

	MYRS	Man-Hours	Cost
Product Drawings	6	12,000	$ 96,000
Process Drawings	4	8,000	64,000
Packaging	2	4,000	32,000
SQUAPS	3	6,000	48,000
Gage Drawings	5	10,000	80,000
Specifications	1	2,000	16,000
Value Analysis	1	2,000	16,000
Engineering	1	2,000	16,000
Standardization	1	2,000	16,000
Contract	.5	1,000	8,000
Miscellaneous	.5	1,000	8,000
	25	50,000	$400,000

Studies Investigation Testing Mathematical Analysis Redesign	6.25	12,500	$100,000

M21
Helicopter Armament Sub System

Source: Production Base Support
Project Close Out Report

APE Project #10325 FY 65 $434,291

PEP

Technical Data Package (TDP)

Source: Production Base Support
Project Justification (Exhibit P16)

Project #66406 FY 66

Forward Area Air Defense Systems	$407,600 (estimate)
PEP - Technical Data Package	
Engineering	8 3/4 MYR @ $175,000
Drafting	10 1/2 MYR @ $105,000
Specifications	1 3/4 MYR @ $ 27,100
Pkg, Test & Eval	1 3/4 MYR @ $ 33,500
Value Analysis	3 1/2 MYR @ $ 67,000

Howitzer, Self Propelled, 105mm/155mm

Source: Data Base TACOM Report for Briefing

M108/M109

Total $ 7,516

AMS		(M108) T195E1	Both	(M109) T196E1
4200	FY 60 APE		$2,655,000	
4200	FY 61 APE		$2,740,000	
4200	FY 61 *	$480,000		$1,641,000

* For Engr Pckg Support Release

Armored Reconnaissance Airborne Assault Vehicle

Source: ARMCOM Data Base

1962 June - Fabrication Pilot Vehicle #1
July - Fabrication Pilot Vehicle #2
Sep - Fabrication Pilot Vehicle #3
1963 Mar - APE Conventional Ammo Initiated
Oct - Fabrication Pilot Vehicles #4, 5, 6, 7 completed

APE	($000)					$19,332	
	Veh	F/C	Spott R Ammo	G/L	Conv Ammo		
FY 63	$7,649	$3,231	$187	$1,638	$1,598--$99		$14,402
Cadillac Gage	5,473 (hardware and engineering not identifiable)						
Ammo				$ 90			
4MTS/Spares	$ 180						
PMSO/ATAC IH	$ 518				Sys Mgmt		
Detroit Diesel 6 Diesel Engines	$ 66						
Allison Div 10 Transmissions	$ 700						
Engineering	$ 714				$1,508		
Frank 8 Sets FC		$3,274 (hardware and engineering not identifiable)					
Spring Armory			$187				
FY 64	$4,735						$ 4,735
FY 65				$ 195			$ 195

Source: Watervliet Arsenal Program Status & Project Records

($000)

Project #10103		$3,787
PEP		1,468
Product Engineering	$855	
Quality Assurance	35	
Pkg and Process Engineering	211	
SQUAPS	94	
Pre Production Planning	198	
Value Engineering	75	
IPF		$2,319
Facilities Hardware	$300	
Testing	270	
Ammunition	260	
Gage Desing & Specs	305	
Gage Acquisition	108	
Pilot Hardware	1,076	

Source: Production Base Support
Project Close Out Report

APE Project #66461

$170,000

PEP

Technical Data Package

SECTION C

Number of Drawings

This section of the Annex contains the number of drawings by size for seventeen weapon systems. The number of drawings exclude MS, Tools and Equipment, and BILI drawings. The number of drawings for these systems is shown for:

Product Drawings

Acceptance Inspection Gage Drawings

D-Sized Equivalent Product Drawings

D-Sized Equivalent Acceptance Inspection Gage Drawings

PRODUCIBILITY ENGINEERING AND PLANNING

DRAWINGS BY SIZE

Number of Product Drawings

Weapon System	TOTAL	A	B	C	D	E	F	G	H	J	K
Rifle, 5.56mm M16	239	16	75	57	47		38	1		4	1
Grenade Launcher, 40mm XM203	72	1	14	21	24		12				
Machine Gun, 7.62mm M60D	259	24	86	71	52		26				
Automatic Gun, 7.62mm M134	103	8	21	47	14	3	10				
Automatic Gun, 20mm M61A1	287 1/	48	91	71	45		30			2	
Automatic Gun, 20mm M39A3	208	41	54	46	26		41				
Automatic Gun, 20mm M139	295	52	124	61	35		23				
Automatic Gun 30mm XM140	271		56	86	70		51		8		
Grenade Launcher, 40mm XM129	142	26	13	36	41		26				
Light Weight Company Mortar 60mm	157	1	77	43	17		19				
Mortar, 4.2mm M30	233	96	70	43	17		7				
Mortar, 81mm M20A1	164	70	57	18	15		4				
Towed Howitzer, 105mm M102	1,750	418	609	371	178	2	172				
Towed Howitzer, 105mm XM204	2,040(e)										
Towed Howitzer, 155mm XM198	2,377	530	774	582	207		256				28
Helicopter Armament System M18A1 2/	327	30	110	118	28	4	36				1
Helicopter Armament System M21 2/	150	40	47	34	12		17				

1/ M61A1 Gun 145
Feed 77
Drive 65

2/ Excludes M134 Automatic Gun

PRODUCIBILITY ENGINEERING AND PLANNING

DRAWINGS BY SIZE

Number of Gage Drawings (Final Acceptance)

Weapon System	TOTAL	A	B	C	D	E	F	G	H	J	K
Rifle, 5.56mm M16	332	8	65	106	118		35				
Grenade Launcher, 40mm XM203	91	4	9	22	31		25				
Machine Gun, 7.6mm M60D	655	147	85	138	197		88				
Automatic Gun, 7.62mm M134	241 1/	42	30	59	74		36				
Automatic Gun, 20mm, M61A1	674 2/	139	88	155	188		104				
Automatic Gun, 20mm M39A3	247	63	63	57	41		23				
Automatic Gun, 20mm M139	256	41	103	60	46		6				
Automatic Gun, 30mm XM140	327	9	9	57	191		61				
Grenade Launcher, 40mm, XM129	206	10	4	51	127		14				
Light Weight Company Mortar 60mm	104	12	15	47	18		12				
Mortar, 4.2mm M30	129	12	60	25	19		13				
Mortar, 81mm M29A1	137	21	57	41	12		6				
Towed Howitzer, 105mm M102	1,243	171	446	282	173		171				
Towed Howitzer, 105mm XM204	1,446(e)	196(e)	484(e)	286(e)	184(e)		296(e)				
Towed Howitzer, 155mm XM198	1,432	176	522	261	181		292				

		TOTAL	A	B	C	D	E	F
1/ M134	Gun	149	24	17	40	45		23
	Feed	92	18	13	19	29		13
2/ M61A1	Gun	401	78	64	78	102		79
	Feed	235	61	19	55	77		23
	Drive	38		5	22	9		2

PRODUCIBILITY ENGINEERING AND PLANNING

DRAWINGS BY SIZE

Number of D-Sized Equivalent Product Drawings

Weapon System	TOTAL	A	B	C	D	E	F	G	H	J	K
D-Size Equivalent Factor		.13	.25	.50	1.00	1.74	1.75	2.0(e)	2.57	2.57	2.57
Rifle, 5.56mm M16	179	2	19	29	47		67	2		10	3
Grenade Launcher, 40mm, XM203	60		4	11	24		21				
Machine Gun 7.62 M60D	159	3	22	36	52		46				
Automatic Gun 7.62mm M134	63	1	4	21	14	5	18				
Automatic Gun 20mm M61A1	168	6	23	36	45		53			5	
Automatic Gun 20mm M39A3	140	5	14	23	26		72				
Automatic Gun 20mm M139	144	7	31	31	35		40				
Automatic Gun 30mm XM140	237		14	43	70		89		21		
Grenade Launcher, 20mm XM129	111	3	3	18	41		46				
Light Weight Company Mortar, 60mm	91		19	22	17		33				
Mortar, 4.2mm M30	81	12	18	22	17		12				
Mortar, 81mm M29A1	54	9	14	9	15		7				
Towed Howitzer, 105mm M102	874	54	152	186	178	3	301				
Towed Howitzer, 105mm XM204	1,059(e)										
Towed Howitzer, 155mm XM198	1,281	69	194	291	207		448				72
HASS M18A1	192	4	28	59	28	7	63				3
HASS M21	76	5	12	17	12		30				

(e) = estimate

PRODUCIBILITY ENGINEERING AND PLANNING

DRAWINGS BY SIZE

Number of D-Sized Equivalent Gage Drawings (Final Acceptance)

Weapon System	TOTAL	A	B	C	D	E	F	G	H	J	K
D-Size Equivalent Factor		.13	.25	.50	1.00		1.75	2.01	2.57	2.57	2.57
Rifle, 5.56mm M16	249	1	16	53	118		61				
Grenade Launcher, 40mm XM203	89	1	2	11	31		44				
Machine Gun 7.62mm M60D	460	19	21	69	197		154				
Automatic Gun 7.62mm M134	180	5	8	30	74		63				
Automatic Gun 20mm M61A1	488	18	22	78	188		182				
Automatic Gun 20mm M39A3	134	8	16	29	41		40				
Automatic Gun 20mm M139	118	5	26	30	46		11				
Automatic Gun 30mm XM140	330	1	2	29	191		107				
Grenade Launcher, 20mm XM129	180	1	1	26	127		25				
Light Weight Company Mortar, 60mm	69	2	4	24	18		21				
Mortar, 4.2mm M30	72	2	15	13	19		23				
Mortar, 81mm M29A1	61	3	14	21	12		11				
Towed Howitzer, 104mm M102	747	22	112	141	173		299				
Towed Howitzer, 105mm XM204	991(e)	25(e)	121(e)	143(e)	184(e)		518(e)				
Towed Howitzer, 155mm XM198	977	23	131	131	181		511				

(e) = estimate

SECTION D

D-Sized Equivalent Drawing Methodology

This section of the annex includes the source data and methodology used in developing D-sized equivalent drawing factors.

D-SIZED EQUIVALENT DRAWING FACTOR

COMPOSITE INDEX

The D-sized equivalent drawing was developed by using the composite average of drafting times and determining the ratio of man-hours for each drawing to the man-hours required to prepare a D-sized drawing. The ratio was developed as follows:

$$\frac{\text{Average Number of Man-hours per Drawing}}{\text{Average Number of Man-hours per D-Sized Drawing}}$$

The factors developed are:

Size Drawing	Average Man-hours per Drawing	D-Sized Equivalent Drawing Factor
A	3.72	.13
B	7.13	.25
C	14.50	.50
D	29.00	1.00
E	50.20	1.73
F	50.67	1.75
H, J, K	74.20 1/	2.56

1/ Drawings of the H through K-size have been combined because of the limited number of data points and their closeness in drafting man-hours.

PRODUCT DRAWINGS

DRAFTING MAN-HOURS

MAN-HOURS PER DRAWING

The composite average of drafting man-hours per drawing outlined in this table was developed from the expert opinion of experienced drafting personnel at various US Army Armament Command laboratories/arsenals as well as an industrial drafting corporation.

TABLE
Man-hours per Drawing

	Drawing Size								
Drawing Size:	A	B	C	D	E	F	H	J	K
	Man-hours per Drawing								
Composite Average:	3.72	7.13	14.50	29.00	50.20	50.67		-----74.20-----	
Watervliet Arsenal	4	5	16	30		50			
Rodman Laboratories									
Tech. Data	4	8	16		40	52			
Aircraft	2	5	10	25	52	50	86		
Artillery	2	4	10	40					70
Tank	2	4	10	16				45	90
C&R Design [1/]									
Space/Rocket	3.4	7.0	13.8	28.0	55.0				
Basic	4	8	16	32	64				
Comprehensive	8	16	24	32	40			80	

1/ Cesare Raimondi, "Estimating Drafting Time-Art, Science, Guesswork," Machine Design, September 7, 1972.

SECTION E

Ratio of Product Engineering Man-hours to Drafting Man-hours

This section contains the methodology for relating the ratio of product engineering man-hours to drafting man-hours.

Ratio of Product Engineering Man-hours to Drafting Man-hours

This table reflects the ratio of product engineering man-hours required for each drafting man-hour. It is a composite of expert opinion from three laboratories in ARMCOM. The purpose of this ratio is to provide the estimator with the level of effort required for product and gage drawings in PEP, given that an estimate of the number of drawings for a weapon system can be determined.

TABLE

Ratio

Engineering Man-hours to Drafting Man-hours

Organization	Engineering Man-hours		Drafting Man-hours
Rodman Laboratory			
Artillery	3		2
Tanks	2		3
XM198 ICE Study	2		1
	7		6
Ratio	1.2	:	1

SECTION F

PEP Definition/Activites

This section contains a definition of PEP and a listing of activities which are included in PEP.

PEP Definition

Producibility Engineering and Planning (PEP)--This element includes costs incurred in assuring the producibility of a developmental weapon system, item, or component. The purpose of PEP is to assure the producibility of a developed end component/item prior to release of production. It involves the engineering tasks undertaken to insure a timely and economic transition from development to production. PEP consists for the most part of the software portion of the former advanced production engineering (APE) and includes but is not limited to, the technical data package. PEP efforts are RDTE funded and usually take place during 6.4 engineering development. PEP effort may take place during 6.3 advanced development and will be primarily associated with the confirmation of producibility of critical components. PEP is applicable to end item efforts for both major and nonmajor weapon systems. PEP should be initiated early during engineering development, but under the circumstances no later than 12 months prior to commencement of DT II/OT II and will extend sufficiently into the low rate initial production phase to insure that the technical data package has incorporated in it all the necessary changes resulting from DT III/OT III and is entirely adequate for full scale production.

Producibility plans will be developed to assure tooling requirements are justified on the basis of the most economical production rate and manufacturing processes. Illustrative of PEP is the procurement of engineering drawings and associated lists that provide the necessary design, engineering, manufacturing, and quality support information to enable the procurement of a specific item and is an RDT&D funded PEP measure.

Producibility Engineering and Planning (PEP) Activities

Technical Data Package (TDP)

- Program management
- Production engineering studies
- Preparation of drawings (product)
- Preparation of lists for drawings
- Packaging design
- Packaging data sheets
- Quality Assurance Provisions (QUAPS)
- Supplementary Quality Assurance Provisions (SQUAPS)
- Specifications
- Purchase descriptions
- Reliability engineering
- Maintainability engineering
- Human factors engineering
- Value engineering
- Progress reporting on work performance
- Maintenance of TDP

Manufacturing Assembly Sequences Method Sheets Schematics
Microfilming
Calibration Information
In-House Support
Mechanical and Electrical Connections Wiring Diagram
Quality Assurance Pamphlets
Details of Unique Processes
Equipment Design
Inspection Test & Evaluation Requirements
Tool and Gage Design
Details of Performance Ratings, Dimensional & Tolerance Data
Computer Modeling/Simulation
Material & Finish Information
Numerical Control Part Program Manuscripts
Producibility Planning Supportive of Initial Production Facilities (IPF) Requirements

SECTION G

Measures of Statistical Credibility

This section contains definitions of the measures of statistical credibility used in this study.

Measures of Statistical Credibility

Coefficient of Determination

The coefficient of determination is the proportion of total variance in the dependent variable that is explained by the independent variable. It provides a relative measure of the average degree of improvement in estimating the magnitudes of the dependent variable by taking into account the magnitudes of the independent variable. The derived value (r^2) falls within the range of 0 (no correlation among the variables) to 1 (perfect correlation among the variables).

Coefficient of Variation

The coefficient of variation (C) can be looked on as a relative standard error. It is a ratio of the standard error of the estimate to the mean of the actual dependent variable.

The coefficient of variation is useful as a summary statistic for a single regression, but is probably most useful for comparing the relative worth of different regressions. As a rule of thumb, a good regression should have a coefficient of variation of .20 or less.

Mean Absolute Percent Deviation

The mean average percent deviation is interpreted as the average percent that the CER values deviate from the actual values.

F Test

A test of significance used to determine if the relationship of the dependent variable to the independent variable may have occurred by chance.

SECTION H

Historical Cost Multipliers

This section of the annex contains the historical cost multipliers used in the study to convert to FY 76 dollars.

PEP

HISTORICAL COST MULTIPLIERS

The table of historical cost multipliers has been used to convert prior year PEP costs to FY 76 dollars. Most of the effort in PEP activities is performed by engineers and engineering technicians. Two bases have been used in developing these factors.

The first basis uses the General Schedule (GS) pay multiplier for in-house effort on the part of government personnel in accomplishing PEP activities.

The second basis uses both the engineering and (GS) pay multiplier for contractor effort in accomplishing PEP activities. The BLS survey for engineers is used from 1961-1975. BLS did not collect information prior to 1961. Therefore, the GS pay multiplier has been used prior to 1961, because of the close proximity between the GS pay multiplier and the engineers between 1961 and 1976.

The R&D multiplier understates the historic multiplier for this type of effort.

PEP

TABLE OF

HISTORICAL COST MULTIPLIERS

		Contractor Effort		
PEP	GS Pay 1/	R&D 2/	Engineers 3/	Engineering Technicians 3/
1950	3.00	2.68		
1956	2.54	2.31		
1960	2.14	2.10		
1961	2.14	2.07	2.07	
1962	2.14		2.02	2.01
1963	2.04		1.93	1.95
1964	1.87		1.88	1.89
1965	1.87		1.82	1.84
1966	1.75		1.76	1.79
1967	1.69		1.68	1.73
1968	1.59		1.60	1.65
1969	1.47		1.51	1.56
1970	1.39		1.43	1.46
1971	1.30		1.35	1.37
1972	1.24		1.28	1.31
1973	1.18		1.22	1.25
1974	1.11		1.16	1.18
1975	1.05		1.07	1.08
1976	1.00		1.00	1.00

1/ Current Wage Developments September 1971, #284 Table 1, US Department of Labor, Bureau of Labor Statistics.

2/ Mr. John Beach, OASD(C):DASD(P/B)PS, 28 Jan 76.

3/ National Survey of Professional Administrative, Technical and Clerical Pay, 1975--Bureau of Labor Statistics.

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13. ABSTRACT

A method of estimating Producibility Engineering and Planning (PEP) costs for proposed armament systems is presented in this report. The method is intended for use in the development phase of the life cycle of an armament system. A cost estimating relationship (CER) has been developed based upon the number of drawings for an armament system. The methodology of CER development as well as historical costs and numbers of drawings are included as an aid to the cost estimator.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Cost Estimating Regression Analysis Cost Analysis Cost Estimating Relationships Producibility Engineering and Planning (PEP) Product Drawings Man-hours Per Drawing						