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LEARNING AND PRODUCTION RATE IN COST ESTIMATING

Production rate is a very important factor in estimating manufacturing costs. Actual price data shows that production rate has a much greater affect on cost than learning. Cost analysts frequently use learning as the only variable in creating cost estimating relationships from historical databases for manufacturing costs. Predicting future costs due to changes in annual and cumulative production quantities should use both learning and production rate to prevent erroneous cost estimates. Large errors in predicting cost and quantities can result due to ignoring rate. High production rate lowers unit cost, and vice versa low production rate increases unit production cost. Lower production rate is a frequent reaction to cutting current costs, but this usually results in a higher unit production cost due to the government and contractor's fixed costs or business base. Production rate is shown to have a much greater impact than learning in manufacturing cost estimating relationships and unit production costs.

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Learning and Production Rate In Cost Estimating

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Learning and Production Rate in Cost Estimating
by Alan G. Markell

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1. Introduction

The cumulative average learning curve theory presumes that as the quantity doubles the cumulative average cost decreases by a constant percentage.

The unit learning curve theory presumes that as the quantity doubles the unit cost decreases by a constant percentage. Both of these theories are based upon observations of aircraft manufacturing plants.

In so far as it concerns Army weapon systems manufacturing cost, I think cost analysts should be using the following basic estimating equation

COST = FUC * (QC ^ B) * (QA ^ C)

where
- COST= average unit manufacturing cost
- FUC = first unit cost
- QC = cumulative production quantity
- B = exponent of learning slope
- QA = annual production quantity, or annual production rate
- C = exponent of rate slope

This is a multi-variant cost estimating relationship with two independent variables, cumulative production quantity and annual production quantity, or in other words, production rate. Learning is related to cumulative production quantity. Rate is related to annual production rate.

People that work with contracts and real data have a feeling that production rate is an important cost factor. For instance, if a production program gets annual quantities reduced, the program management staff expects an increase in unit price although a cost estimating relationship using learning only, that is, without a rate factor, would not show an increase in price.

The Selected Acquisition Report addresses rate with the reporting of Maximum Economic Rate for production in section 17, Production Rate Data. DOD 5000.2-M, Department of Defense Manual, Defense Acquisition Management Documentation and Reports, Part 17, Attachment 1 and Attachment 2, Selected Acquisition Report Preparation Instructions, February 1991 gives the following definition:

> **Maximum Economic Production Rate** is defined as the production rate at which the lowest unit cost is attainable with the facilities and tooling currently programed to be available.

The SAR Handbook addresses rate with the following definition:

Minimum Sustaining Production Rate is defined as the production rate necessary to keep production lines open while maintaining a responsive vendor/supplier base. Any reduction in production below the minimum sustaining rate causes a dramatic rise in unit cost.

Cost analysts that develop cost estimating relationships with historical data usually assume a single independent variable, cumulative production, and disregard production rate, that is, learning is the only factor that affects cost; rate has no affect. This is a convenient and simplistic assumption. Their resulting cost estimating relationship is like the blind man's description of an elephant; if he grabs the elephant's tail he says an elephant is like a rope; if he grabs the elephants leg, he says an elephant is like a tree. This is after-the-fact cost estimating.

For cost analysts that must estimate future costs, and the important word is future, using cumulative production quantity or learning without consideration for annual production rate leads to erroneous cost estimates. This is before-the-fact cost estimating.

With the information I am about to show you, you will see that annual production rate has a much greater affect on cost than cumulative production quantity or learning. You will see that cumulative production quantity or learning is a relatively minor factor.

2. Actual Data

Actual cost data submitted to Air-to-Ground Missile Systems Project Office will illustrate the importance of production rate. For each fiscal year, the contractor provided to AGMS Project Office a yearly cumulative average unit price in then-year dollars for each quantity of missiles in each fiscal year, similar to as show in figure 1. This cost data is taken from Contract DAAH01-90-C-0323, Modification PZ0004, Attachments 10, 11, 12, and 13.

3. Data Manipulation

I took the price data which was submitted to Air-to-Ground Missile Systems Project Office in escalated dollars and converted them to FY93 constant dollars to prepare the data for log-linear regression. Next I take the logarithm of these constant dollars values and annual production quantities. I used Lotus 1-2-3 to perform single variant log-linear regression. The independent variable is annual cumulative production quantity, X. The dependent variable, Y, is the cumulative average unit cost with respect to one annual lot. These regressions gives me the first unit cost and slope for each year individually. The graph of Hellfire II missiles unit price verses quantity for the individual years are shown on the figure 2.

To quantify the affects of two independent variables, learning and production rate, multi-variant log-linear regression was performed on the price data. The independent variables are cumulative production quantity, QC, and annual production rate, QA. The dependent variable, Y, is the cumulative average unit price.

For the regression, I normalized the production rate quantity, QA. In the case of Hellfire II, I normalized QA such that 6,300 units in a year equals 1. For instance, 2,100 normalized equals 0.33. The quantity of 6,300 is the Maximum Economic Rate. The reason for normalizing QC, is that in the equation Y = FUC * [QC ^ B] * [QA ^ C], the production rate term, QA^C, equals 1 and has no effect when Maximum Economic Rate occurs; only learning has an effect.

Intuitive, this makes good sense to me, but it is not totally necessary. The predicted cost is exactly the same value irregardless of whether the production rate factor is normalized or not.

I used Lotus 1-2-3 to perform multi-variant log-linear regression. The actual and regression average unit price verses quantity of Hellfire II missiles are shown on figure 3.

4. Analysis

Figure 4 shows the coefficients due to learning, rate, and the product of learning and rate. The graph in figure 4 clearly shows rate is the dominate factor. Learning is almost constant irregardless of cumulative production quantity.

The values of first unit cost and slope for each year and the combined years are shown on figure 5 for Hellfire II Missile.

Hellfire II missile cost data shows the learning factor has a 98% slope and production rate factor has an 85% slope.

A Slope value of 98% shows that Learning is an insignificant factor in cost. The production rate factor has an overwhelmingly more important affect on cost than learning.

Using production rate as a cost factor provides a plausible, logical explanation and justification for cost estimates. Using a learning factor, without regard to rate, sometimes gives ridiculous cost estimates.

In actual practice, Air-to-Ground Missile Systems Project Office uses a separate cost estimating equation for each individual year rather than one equation for all years.

5. Examples

Example 1 - Stretched-out Production Program - Cost Impact

The following is an example of how a stretched-out production program impacts cost. In this example, cumulative production quantity remains the same, but the production rate is reduced by 50% from the original plan. Intuitively, stretching-out a production program should increase total costs, but using learning factor only, and disregarding production rate, we will have a 2% increase in cost in a stretched-out program over the original compressed production schedule. This 2% is due to inflation. For example figure 6 shows cost with learning only and it shows the same program with learning and production rate as a factor. The cost are very different between the two different scenarios. The "learning and rate" cost estimate is 21% more for the same quantity, but slower production rate. By using "learning only" we would have under-estimated cost by 16%. The cost estimate where rate is a factor gives a more accurate and plausible cost estimate. To perform better cost estimates, we need to show the affect of production rate. Production rate substantial below maximum economic rate, increases unit production costs.

Example 2 - low coefficient of determination, R^2

In the following example, the coefficient of determination, R^2, is shown to have a low value due to not taking production rate into account. The coefficient of determination, R^2, is a measure of the closeness of fit of the prediction equation to the actual data. In the cost world, a low R^2 means our prediction equation is unreliable, and there is a weak relationship between quantity and price.

The regression of the maximum quantities in all years gives an R^2 value of .63.

The regression of minimum quantities in all years gives an R^2 value of .2.

We have an R^2 of .96 using the same points and having prior knowledge of the affect of rate and learning. Figure 7 shows these curves.

6. Conclusion

For manufacturing costs, we should be using the equation COST = FUC * (QC^B)(QA^C) where QC equals cumulative quantity and QA equals annual production quantity. Or in other words, QC^B is the learning factor and QA^C is the rate factor.

New major weapon systems should have rate as a factor in estimating future manufacturing costs. A means to determine the rate and learning factors is to have this a part of the Design-To-Cost Program.

Production rate at maximum economic rate decreases unit production costs.

Producing the same quantity over more years will increase unit costs.

A decrease in production rate should increase unit production price, but using "learning factor only", we would NOT have an increase in unit production costs, which is wrong.

Cumulative production quantity, or experience, does not cause cost reductions, but rather cumulative production quantity (experience) provides an opportunity to reduce costs by alerting management of opportunities to reduce cost. Left unmanaged, costs increase. Cost reductions are due to a concerted effort to lower costs.

I would like to mention that using learning and rate factors are available on the new Department of Defense Baseline Cost Model ACEIT. They are also available on MICOM's Pices.

7. References

HELLFIRE Optimized Missile System (HOMS)
Martin Marietta Corporation
Contract DAAH01-90-C-0323, Modification PZ0004
Attachments 10, 11, 12, and 13
Prices for Production Options
dated December 1989

DOD 5000.2-M, Department of Defense Manual, Defense Acquisition Management Documentation and Reports, Part 17, Attachment 1 and Attachment 2, Selected Acquisition Report Preparation Instructions, February 1991

Selected Acquisition Report Handbook

Learning and Production Rate in Cost Estimating

FIGURES

First Fiscal Year Procurement

Quantity	Price (TY$)
1,300	$32,903
1,501	$32,900
1,502	$32,896
1,503	$32,893
.	.
.	.
5,000	$27,400

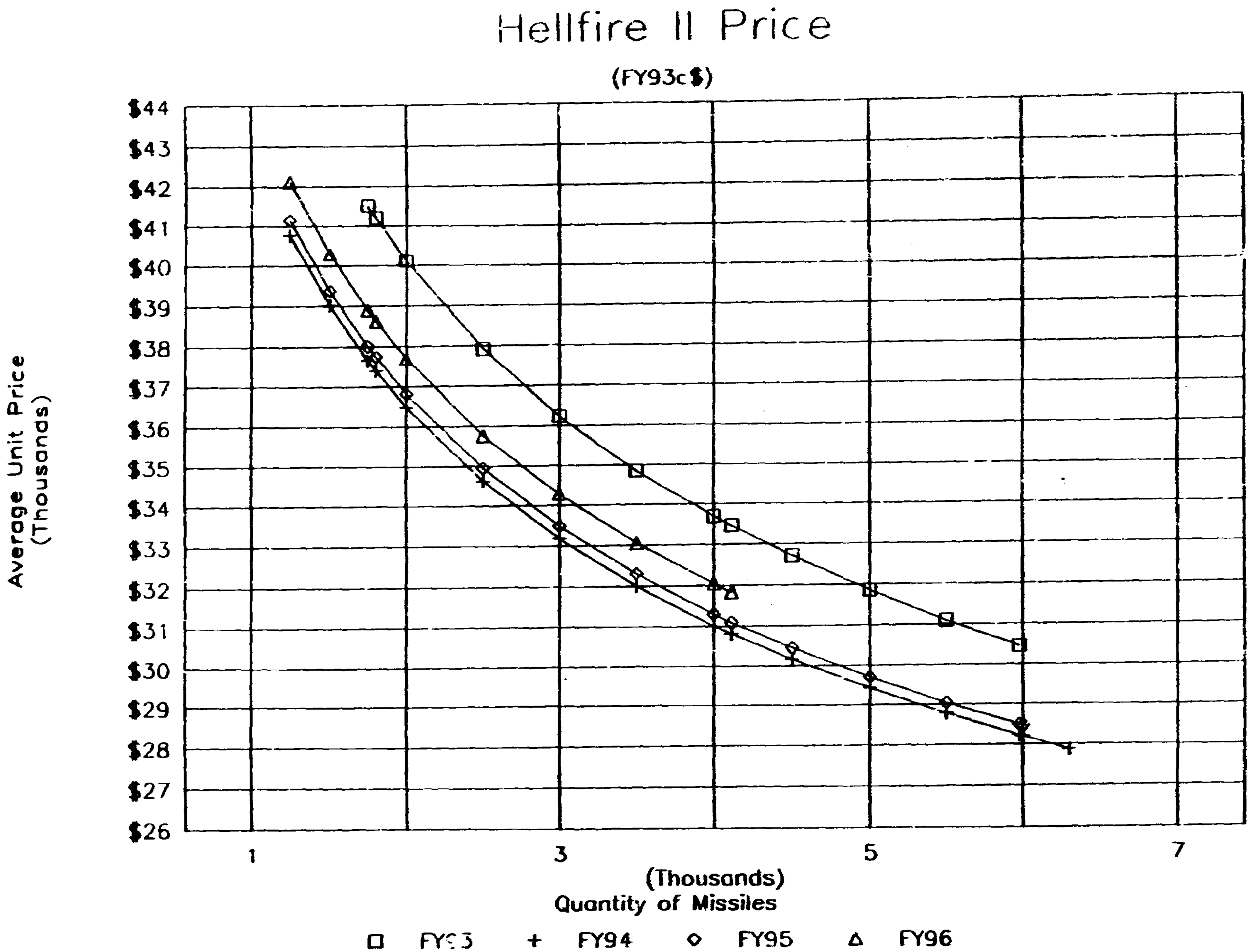
Second Fiscal Year Procurement

Quantity	Price (TY$)
2,000	$28,780
2,001	$28,778
2,002	$28,776
2,003	$28,773
.	.
.	.
6,000	$24,407

Third Fiscal Year Procurement

Quantity	Price (TY$)
2,500	$27,832
2,501	$27,831
2,502	$27,829
2,503	$27,827
.	.
.	.
6,000	$24,407

figure 1



Hellfire II Price
(FY93c$)
Average Unit Price
(Thousands)
$44
$43
$42
$41
$40
$39
$38
$37
$36
$35
$34
$33
$32
$31
$30
$29
$28
$27
$26
1
3
5
7
(Thousands)
Quantity of Missiles
FY93
FY94
FY95
FY96

figure 2

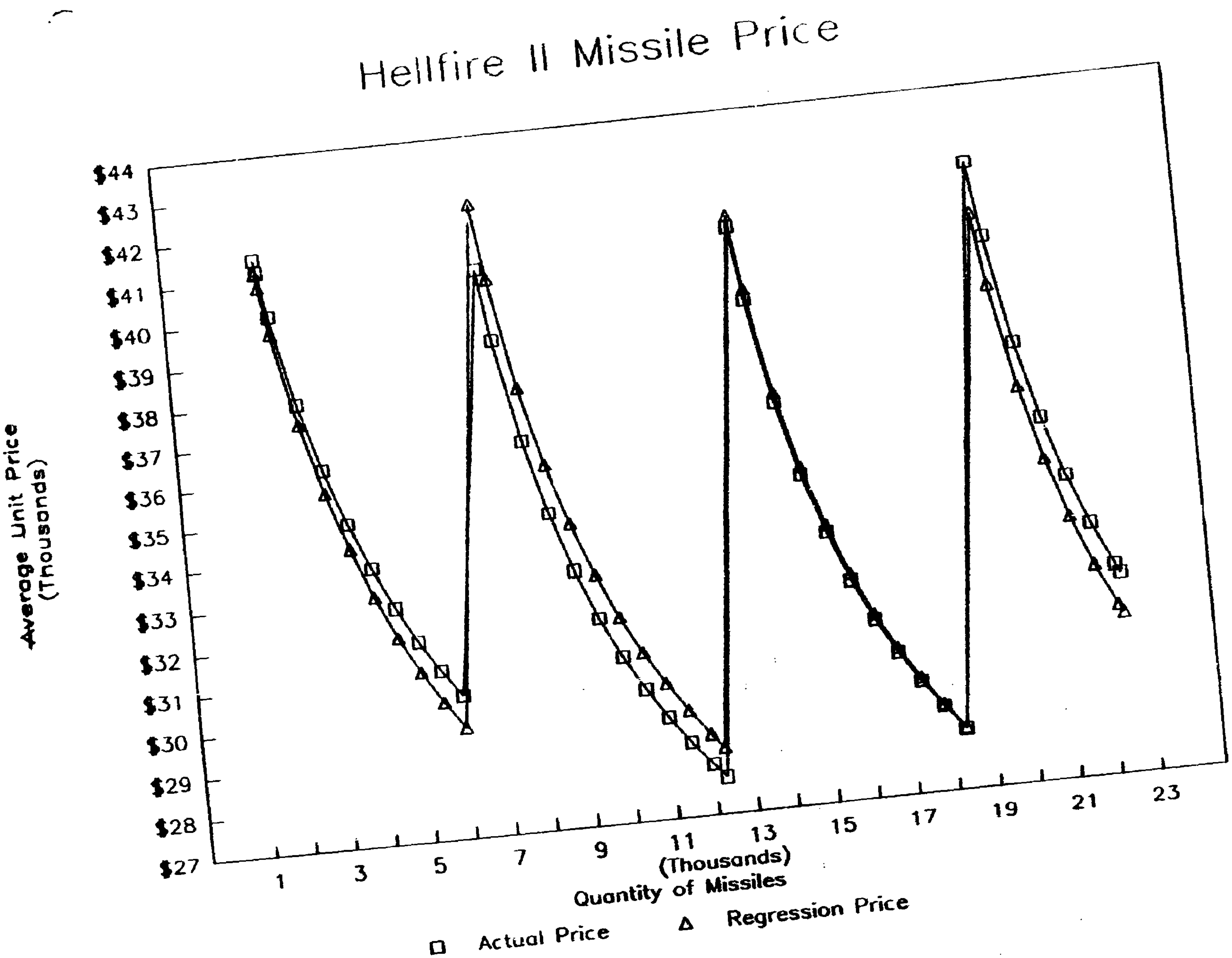

Hellfire II Missile Price
Average Unit Price
(Thousands)
$44
$43
$42
$41
$40
$39
$38
$37
$36
$35
$34
$33
$32
$31
$30
$29
$28
$27
1
3
5
7
9
11
13
15
17
19
21
23
(Thousands)
Quantity of Missiles
Actual Price
Regression Price

figure 3

Hellfire II

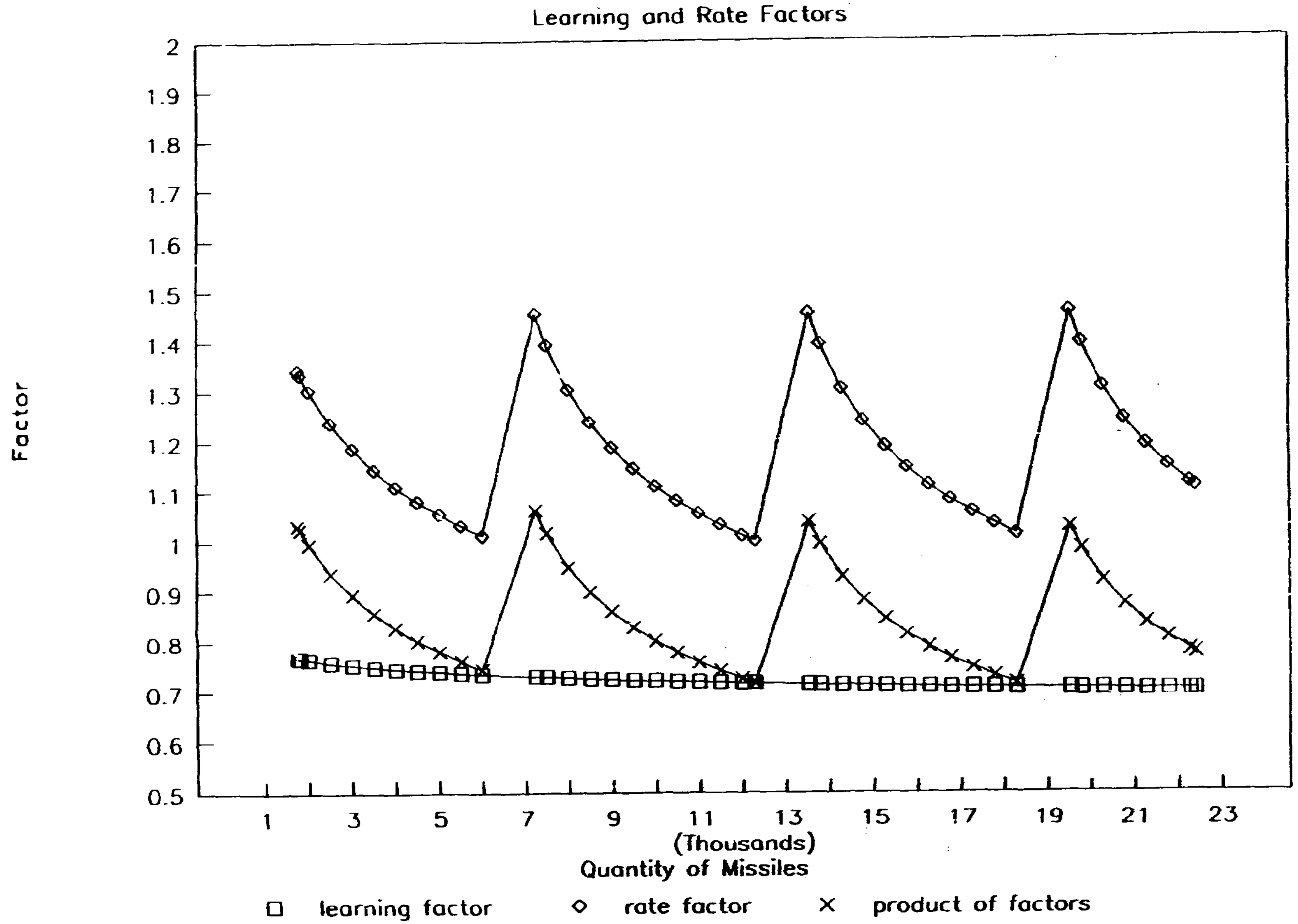


figure 4A

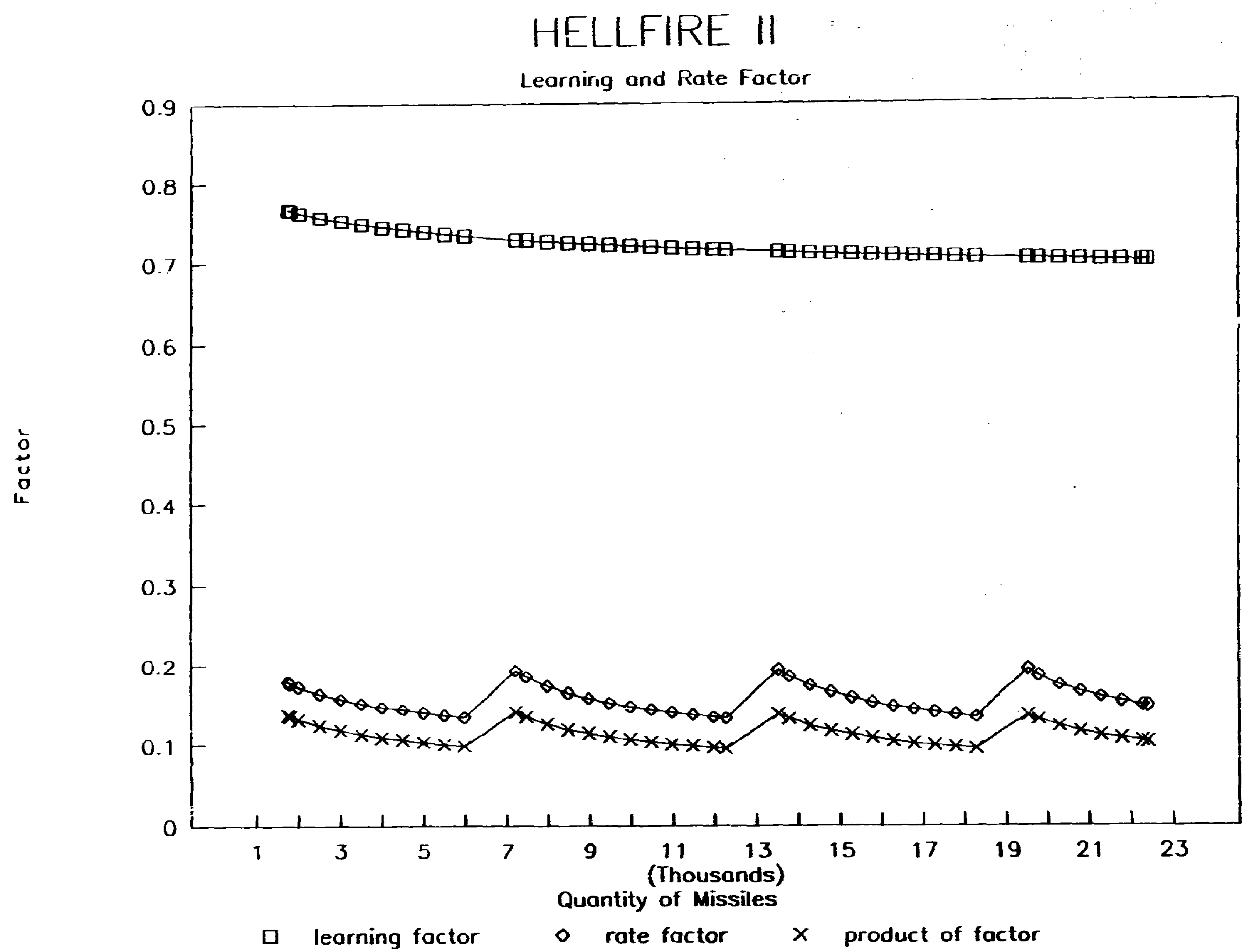

HELLFIRE II
Learning and Rate Factor
Factor
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
3
5
7
9
11
13
15
17
19
21
23
(Thousands)
Quantity of Missiles
learning factor
rate factor
product of factor

figure 4B

HELLFIRE II Price

year	FUC (FY93c$)	learning slope	rate slope
FY93	$271,949		84.0%
FY94	$216,802		85.0%
FY95	$218,817		85.0%
FY96	$223,971		85.0%
all years	$300,594	97.6%	85.2%

figure 5

Procurement Scenarios

	FY93	FY94	FY95	FY96	TOTAL		
ORIGINAL PLAN							
annual quantity	4,000	4,000	0	0	8,000		
cost (mFY93c$)	$132.1	$128.9	$0	$0	$261.0		
cost (mTY$)	$137.9	$137.5	$0	$0	$275.5		

LEARNING FACTOR ONLY (without Rate Factor)

cost = $38,218 * (QC ^ -0.0176) * QC

REDUCE RATE BY 50%						Change	
annual quantity	2,000	2,000	2,000	2,000	8,000	-50%	production rate
cumulative quantity	2,000	4,000	6,000	8,000	8,000	0%	total quantity
cost (mFY93c$)	$66.9	$65.2	$64.6	$64.3	$261.0	0%	cost (mFY93c$)
cost (mTY$)	$69.8	$69.6	$70.5	$71.8	$281.6	2%	cost (mTY$)

"Reduce Rate by 50%" scenario causes a 2% increase in cost.

LEARNING AND RATE FACTORS

cost = $300,694 * (QC ^ (-0.035395) * (QA ^ -.230860) * QA

REDUCE RATE BY 50%						Change	
annual quantity	2,000	2,000	2,000	2,000	8,000	-50%	production rate
cumulative quantity	2,000	4,000	6,000	8,000	8,000	0%	total quantity
cost (mFY93c$)	$79.5	$77.5	$76.4	$75.6	$309.0	18%	cost (mFY93c$)
cost (mTY$)	$82.9	$82.7	$83.4	$84.3	$333.4	21%	cost (mTY$)

"Reduce Rate by 50%" scenario causes a cost increase of $57.9 million or 21%.

Comparing Learning and Rate Scenario to Learning Only Scenario
"Reduce Rate by 50%" scenario causes an under-estimation of cost of $51.8 million or 18%.

figure 6

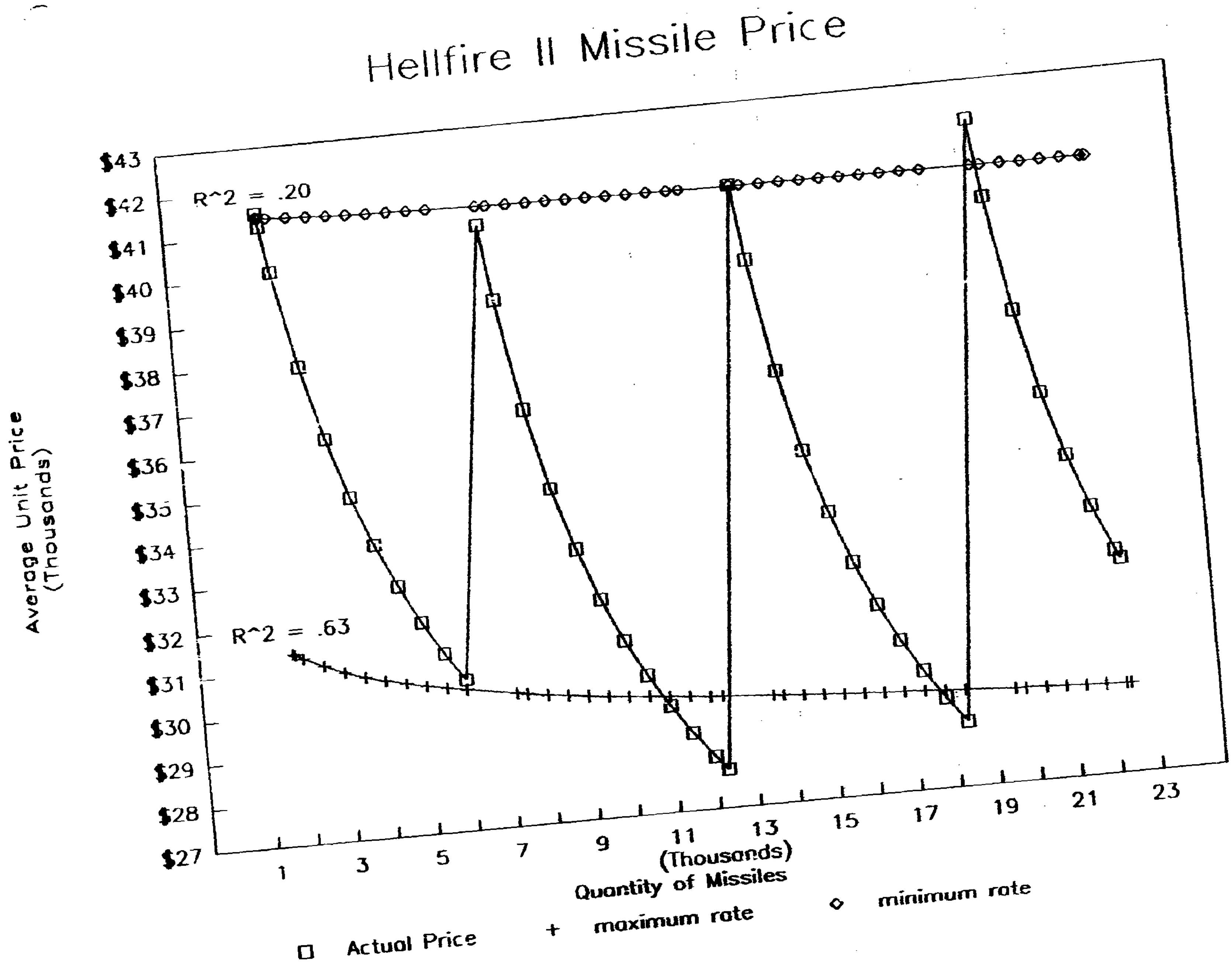

Hellfire II Missile Price
Average Unit Price
(Thousands)
$43
$42
$41
$40
$39
$38
$37
$36
$35
$34
$33
$32
$31
$30
$29
$28
$27
R^2 = .20
R^2 = .63
1
3
5
7
9
11
13
15
17
19
21
23
(Thousands)
Quantity of Missiles
Actual Price
maximum rate
minimum rate

figure 7

Learning and Production Rate in Cost Estimating

APPENDIX

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HELLFIRE II in FY93c$ for FY93 procurement

FY93esc$ to FY93c$ conversion factor = 0.957854 = 1 / 1.0440

X Quantity	Propose (FY93esc$)	Y Propose (FY93c$)	Regress (FY93c$)	delta	*	log(X)	log(Y)	Regress log(Y)
1			$271,949		*	0.00000		5.43449
1,747	$43,340	$41,513	$41,513	$0.17	*	3.24229	4.61819	4.61819
1,800	$43,015	$41,202	$41,202	$0.06	*	3.25527	4.61492	4.61492
2,000	$41,889	$40,124	$40,123	$0.09	*	3.30103	4.60340	4.60340
2,500	$39,600	$37,931	$37,931	($0.45)	*	3.39794	4.57899	4.57900
3,000	$37,824	$36,230	$36,230	$0.19	*	3.47712	4.55907	4.55906
3,500	$36,384	$34,851	$34,851	$0.02	*	3.54407	4.54221	4.54221
4,000	$35,181	$33,698	$33,698	($0.12)	*	3.60206	4.52761	4.52761
4,500	$34,153	$32,714	$32,714	($0.18)	*	3.65321	4.51473	4.51473
5,000	$33,259	$31,857	$31,857	($0.14)	*	3.69897	4.50321	4.50321
5,500	$32,471	$31,102	$31,102	$0.42	*	3.74036	4.49280	4.49279
5,976	$31,799	$30,459	$30,459	($0.05)	*	3.77641	4.48371	4.48371

Regression Output:

Constant	5.4344875	$271,949
Std Err of Y Est	0.0000030	
R Squared	0.9999999	
No. of Observations	11	
Degrees of Freedom	9	

X Coefficient(s) -0.281766 slope = 83.99%
Std Err of Coef. 0.0000049

Y	=	$271,949	*	X	^	b
$30,459	=	$271,949	*	5,976	^	-0.28176

HELLFIRE II in FY93c$ for FY94 procurement

FY94esc$ to FY93c$ conversion factor = 0.937294 = 1 / 1.0669

X Quantity	Propose (FY94esc$)	Y Propose (FY93c$)	Regress (FY93c$)	delta	*	log(X)	log(Y)	Regress log(Y)
1			$216,802		*	0.00000		5.33606
1,245	$43,498	$40,770	$40,771	($0.29)	*	3.09517	4.61035	4.61035
1,500	$41,639	$39,028	$39,028	$0.13	*	3.17609	4.59138	4.59138
2,000	$38,923	$36,482	$36,482	$0.12	*	3.30103	4.56208	4.56208
2,500	$36,939	$34,623	$34,623	$0.19	*	3.39794	4.53936	4.53936
3,000	$35,393	$33,174	$33,174	($0.00)	*	3.47712	4.52079	4.52079
3,500	$34,137	$31,996	$31,996	$0.35	*	3.54407	4.50510	4.50510
4,000	$33,084	$31,009	$31,010	($0.39)	*	3.60206	4.49149	4.49150
4,500	$32,183	$30,165	$30,165	($0.23)	*	3.65321	4.47950	4.47951
5,000	$31,398	$29,429	$29,429	$0.05	*	3.69897	4.46878	4.46878
5,500	$30,704	$28,779	$28,779	($0.07)	*	3.74036	4.45907	4.45907
6,000	$30,084	$28,198	$28,198	($0.02)	*	3.77815	4.45021	4.45021
6,300	$29,742	$27,877	$27,877	$0.16	*	3.79934	4.44525	4.44524

Regression Output:

Constant	5.3360629	$216,802
Std Err of Y Est	0.0000029	
R Squared	0.9999999	
No. of Observations	12	
Degrees of Freedom	10	

X Coefficient(s) -0.234466 slope = 85.00%
Std Err of Coef. 0.0000038

Y	=	$216,802	*	X	^	b
$27,877	=	$216,802	*	6,300	^	-0.23446

HELLFIRE II in FY93c$ for FY95 procurement

FY95escS to FY93c$ conversion factor = 0.916758 = 1 / 1.0908

X Quantity	Propose (FY95esc$)	Y Propose (FY93c$)	Regress (FY93c$)	delta	*	log(X)	log(Y)	Regress log(Y)
1			$218,817		*	0.00000		5.34008
1,245	$44,886	$41,150	$41,149	$0.23	*	3.09517	4.61437	4.61436
1,500	$42,967	$39,390	$39,390	$0.02	*	3.17609	4.59539	4.59539
2,000	$40,164	$36,821	$36,821	($0.32)	*	3.30103	4.56609	4.56610
2,500	$38,117	$34,944	$34,944	$0.02	*	3.39794	4.54337	4.54337
3,000	$36,522	$33,482	$33,482	$0.12	*	3.47712	4.52481	4.52481
3,500	$35,225	$32,293	$32,293	($0.38)	*	3.54407	4.50911	4.50911
4,000	$34,140	$31,298	$31,298	$0.33	*	3.60206	4.49552	4.49551
4,500	$33,210	$30,446	$30,445	$0.25	*	3.65321	4.48352	4.48352
5,000	$32,399	$29,702	$29,702	($0.34)	*	3.69897	4.47279	4.47279
5,500	$31,683	$29,046	$29,046	($0.34)	*	3.74036	4.46308	4.46309
6,000	$31,044	$28,460	$28,459	$0.42	*	3.77815	4.45423	4.45423

Regression Output:

Constant	5.3400807	$218,817
Std Err of Y Est	0.0000044	
R Squared	0.9999999	
No. of Observations	11	
Degrees of Freedom	9	

X Coefficient(s) -0.234467 slope = 85.00%

Std Err of Coef. 0.0000050

Y	=	$218,817	*	X	^	b
$28,459	=	$218,817	*	6,000	^	-0.23446

HELLFIRE II in FY93c$ for FY96 procurement

FY96esc$ to FY93c$ conversion factor = 0.896941 = 1 / 1.1149

X Quantity	Propose (FY95esc$)	Y Propose (FY93c$)	Regress (FY93c$)	delta	*	log(X)	log(Y)	Regress log(Y)
1			$223,971		*	0.00000		5.35019
1,245	$46,959	$42,119	$42,120	($0.23)	*	3.09517	4.62448	4.62449
1,500	$44,952	$40,319	$40,319	$0.10	*	3.17609	4.60551	4.60551
2,000	$42,020	$37,689	$37,689	$0.16	*	3.30103	4.57622	4.57622
2,500	$39,878	$35,768	$35,768	$0.09	*	3.39794	4.55350	4.55350
3,000	$38,209	$34,271	$34,271	($0.12)	*	3.47712	4.53493	4.53493
3,500	$36,853	$33,055	$33,055	$0.18	*	3.54407	4.51924	4.51923
4,000	$35,717	$32,036	$32,036	$0.11	*	3.60206	4.50564	4.50564
4,114	$35,482	$31,825	$31,826	($0.29)	*	3.61426	4.50277	4.50278

Regression Output:

Constant	5.3501920	$223,971
Std Err of Y Est	0.0000024	
R Squared	0.9999999	
No. of Observations	8	
Degrees of Freedom	6	

X Coefficient(s) -0.234464 slope = 85.00%

Std Err of Coef. 0.0000047

Y	=	$223,971	*	X	^	b
$31,826	=	$223,971	*	4,114	^	-0.23446

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HELLFIRE II MULTI-VARIANT REGRESSION

Regression Output:		
Constant	5.477980	$300,594
Std Err of Y Est	0.010587	
R Squared	0.962173	
No. of Observations	42	
Degrees of Freedom	39	
	Learning	Rate
X Coefficient(s)	-0.035395	-0.23086
Std Err of Coef.	0.0051563	0.007788
slope =	97.58%	85.21%

COST = $300,594 * (QC ^ -0.035395) * (QA ^ -0.23086)

QC Qty Cumulative	QA Qty annual	Proposal Price (TY$)	Y Proposal Price (FY93c$)	regression (FY93c$)	learn factor	rate factor	factors product	Propose vs Regress	delta	*	log(QC)	log(QA)	log(Y)
1	1			$300,594	1.00	1.00	1.00			*		0.000	
1,747	1,747	$43,340	$41,513	$41,180	0.77	0.18	0.14	0.8%	$333	*	3.242	3.242	4.618
1,800	1,800	$43,015	$41,202	$40,854	0.77	0.18	0.14	0.8%	$348	*	3.255	3.255	4.615
2,000	2,000	$41,889	$40,124	$39,724	0.76	0.17	0.13	1.0%	$400	*	3.301	3.301	4.603
2,500	2,500	$39,600	$37,931	$37,433	0.76	0.16	0.12	1.3%	$499	*	3.398	3.398	4.579
3,000	3,000	$37,824	$36,230	$35,659	0.75	0.16	0.12	1.6%	$571	*	3.477	3.477	4.559
3,500	3,500	$36,384	$34,851	$34,225	0.75	0.15	0.11	1.8%	$626	*	3.544	3.544	4.542
4,000	4,000	$35,181	$33,698	$33,029	0.75	0.15	0.11	2.0%	$669	*	3.602	3.602	4.528
4,500	4,500	$34,153	$32,714	$32,010	0.74	0.14	0.11	2.2%	$704	*	3.653	3.653	4.515
5,000	5,000	$33,259	$31,857	$31,124	0.74	0.14	0.10	2.3%	$733	*	3.699	3.699	4.503
5,500	5,500	$32,471	$31,102	$30,344	0.74	0.14	0.10	2.4%	$758	*	3.740	3.740	4.493
5,976	5,976	$31,799	$30,458	$29,681	0.74	0.13	0.10	2.6%	$778	*	3.776	3.776	4.484
7,221	1,245	$43,498	$40,770	$42,349	0.73	0.19	0.14	-3.9%	($1,578)	*	3.859	3.095	4.610
7,476	1,500	$41,639	$39,028	$40,516	0.73	0.18	0.13	-3.8%	($1,488)	*	3.874	3.176	4.591
7,976	2,000	$38,923	$36,482	$37,826	0.73	0.17	0.13	-3.7%	($1,343)	*	3.902	3.301	4.562
8,476	2,500	$36,939	$34,623	$35,849	0.73	0.16	0.12	-3.5%	($1,227)	*	3.928	3.398	4.539
8,976	3,000	$35,393	$33,174	$34,302	0.72	0.16	0.11	-3.4%	($1,128)	*	3.953	3.477	4.521
9,476	3,500	$34,137	$31,996	$33,039	0.72	0.15	0.11	-3.3%	($1,043)	*	3.977	3.544	4.505
9,976	4,000	$33,084	$31,009	$31,978	0.72	0.15	0.11	-3.1%	($969)	*	3.999	3.602	4.491
10,476	4,500	$32,183	$30,166	$31,066	0.72	0.14	0.10	-3.0%	($901)	*	4.020	3.653	4.480
10,976	5,000	$31,398	$29,429	$30,270	0.72	0.14	0.10	-2.9%	($841)	*	4.040	3.699	4.469
11,476	5,500	$30,704	$28,779	$29,564	0.72	0.14	0.10	-2.7%	($785)	*	4.060	3.740	4.459
11,976	6,000	$30,084	$28,198	$28,933	0.72	0.13	0.10	-2.6%	($735)	*	4.078	3.778	4.450

12,276	6,300	$29,742	$27,877	$28,584	0.72	0.13	0.10	-2.5%	($707)*	4.089	3.799	4.445
13,521	1,245	$44,886	$41,150	$41,419	0.71	0.19	0.14	-0.7%	($269)*	4.131	3.095	4.614
13,776	1,500	$42,967	$39,390	$39,649	0.71	0.18	0.13	-0.7%	($259)*	4.139	3.176	4.595
14,276	2,000	$40,164	$36,821	$37,054	0.71	0.17	0.12	-0.6%	($234)*	4.156	3.301	4.566
14,776	2,500	$38,117	$34,944	$35,151	0.71	0.16	0.12	-0.6%	($207)*	4.170	3.398	4.543
15,276	3,000	$36,522	$33,482	$33,662	0.71	0.16	0.11	-0.5%	($181)*	4.184	3.477	4.526
15,776	3,500	$35,225	$32,293	$32,449	0.71	0.15	0.11	-0.5%	($156)*	4.198	3.544	4.509
16,276	4,000	$34,140	$31,298	$31,429	0.71	0.15	0.10	-0.4%	($131)*	4.212	3.602	4.496
16,776	4,500	$33,210	$30,446	$30,553	0.71	0.14	0.10	-0.4%	($107)*	4.225	3.653	4.484
17,276	5,000	$32,399	$29,702	$29,788	0.71	0.14	0.10	-0.3%	($86)*	4.237	3.699	4.473
17,776	5,500	$31,683	$29,046	$29,110	0.71	0.14	0.10	-0.2%	($64)*	4.250	3.740	4.463
18,276	6,000	$31,044	$28,460	$28,503	0.71	0.13	0.09	-0.2%	($43)*	4.262	3.778	4.454
19,521	1,245	$46,959	$42,119	$40,884	0.70	0.19	0.14	2.9%	$1,235 *	4.291	3.096	4.624
19,776	1,500	$44,952	$40,319	$39,146	0.70	0.18	0.13	2.9%	$1,175 *	4.296	3.176	4.606
20,276	2,000	$42,020	$37,689	$36,597	0.70	0.17	0.12	2.9%	$1,092 *	4.307	3.301	4.576
20,776	2,500	$39,878	$35,768	$34,730	0.70	0.16	0.12	2.9%	$1,039 *	4.318	3.398	4.553
21,276	3,000	$38,209	$34,271	$33,270	0.70	0.16	0.11	2.9%	$1,001 *	4.328	3.477	4.535
21,776	3,500	$36,853	$33,056	$32,080	0.70	0.15	0.11	2.9%	$976 *	4.338	3.544	4.519
22,276	4,000	$35,717	$32,036	$31,082	0.70	0.15	0.10	3.0%	$954 *	4.348	3.602	4.506
22,390	4,114	$35,482	$31,825	$30,875	0.70	0.15	0.10	3.0%	$950 *	4.350	3.614	4.503

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HELLFIRE II MULTI-VARIANT REGRESSION

Regression Output:

Constant	4.600850	$39,889
Std Err of Y Est	0.010587	
R Squared	0.962173	
No. of Observations	42	
Degrees of Freedom	39	
	Learning	Rate
X Coefficient(s)	-0.0353	-0.23086
Std Err of Coef.	0.00515	0.007788
slope =	97.58%	85.21%

COST = $39,889 * (QC ^ -0.035395) * (QA ^ -0.23086)

QC Qty Cumulative	QA* Qty annual	Proposal Price (TY$)	Y Proposal Price (FY93c$)	regression (FY93c$)	learn factor	rate factor	factors product	Propose vs Regress	delta	*	log(QC)	log(QA)	log(Y)
										*			
1	0.0002			$300,594	1.00	7.54	7.54			*	0.000	-3.799	
1,747	0.277	$43,340	$41,513	$41,180	0.77	1.34	1.03	0.8%	$333	*	3.242	-0.557	4.618
1,800	0.286	$43,015	$41,202	$40,854	0.77	1.34	1.02	0.8%	$348	*	3.255	-0.544	4.615
2,000	0.317	$41,889	$40,124	$39,724	0.76	1.30	1.00	1.0%	$400	*	3.301	-0.498	4.603
2,500	0.397	$39,600	$37,931	$37,433	0.76	1.24	0.94	1.3%	$499	*	3.398	-0.401	4.579
3,000	0.476	$37,824	$36,230	$35,659	0.75	1.19	0.89	1.6%	$571	*	3.477	-0.322	4.559
3,500	0.556	$36,384	$34,851	$34,225	0.75	1.15	0.86	1.8%	$626	*	3.544	-0.255	4.542
4,000	0.635	$35,181	$33,698	$33,029	0.75	1.11	0.83	2.0%	$669	*	3.602	-0.197	4.528
4,500	0.714	$34,153	$32,714	$32,010	0.74	1.08	0.80	2.2%	$704	*	3.653	-0.146	4.515
5,000	0.794	$33,259	$31,857	$31,124	0.74	1.05	0.78	2.3%	$733	*	3.699	-0.100	4.503
5,500	0.873	$32,471	$31,102	$30,344	0.74	1.03	0.76	2.4%	$758	*	3.740	-0.059	4.493
5,976	0.949	$31,799	$30,459	$29,681	0.74	1.01	0.74	2.6%	$778	*	3.776	-0.023	4.484
7,221	0.198	$43,498	$40,770	$42,349	0.73	1.45	1.06	-3.9%	($1,578)	*	3.859	-0.704	4.610
7,476	0.238	$41,639	$39,028	$40,516	0.73	1.39	1.02	-3.8%	($1,488)	*	3.874	-0.623	4.591
7,976	0.317	$38,923	$36,482	$37,826	0.73	1.30	0.95	-3.7%	($1,343)	*	3.902	-0.498	4.562
2,476	0.397	$36,939	$34,623	$35,849	0.73	1.24	0.90	-3.5%	($1,227)	*	3.028	-0.401	4.539
8,976	0.476	$35,393	$33,174	$34,302	0.72	1.19	0.86	-3.4%	($1,128)	*	3.953	-0.322	4.521
9,476	0.556	$34,137	$31,996	$33,039	0.72	1.15	0.83	-3.3%	($1,043)	*	3.977	-0.255	4.505
9,976	0.635	$33,084	$31,009	$31,978	0.72	1.11	0.80	-3.1%	($969)	*	3.999	-0.197	4.491
10,475	0.714	$32,183	$30,165	$31,066	0.72	1.08	0.78	-3.0%	($901)	*	4.020	-0.146	4.480
10,976	0.794	$31,398	$29,429	$30,270	0.72	1.05	0.76	-2.9%	($841)	*	4.040	-0.100	4.469
11,476	0.873	$30,704	$28,779	$29,564	0.72	1.03	0.74	-2.7%	($786)	*	4.060	-0.059	4.459
11,976	0.952	$30,084	$28,198	$28,933	0.72	1.01	0.73	-2.6%	($735)	*	4.078	-0.021	4.450
12,276	1.000	$29,742	$27,877	$28,584	0.72	1.00	0.72	-2.5%	($707)	*	4.089	0.000	4.445
13,521	0.198	$44,886	$41,150	$41,419	0.71	1.45	1.04	-0.7%	($269)	*	4.131	-0.704	4.614
13,776	0.238	$42,967	$39,390	$39,649	0.71	1.39	0.99	-0.7%	($259)	*	4.139	-0.623	4.595
14,276	0.317	$40,164	$36,821	$37,054	0.71	1.30	0.93	-0.6%	($234)	*	4.155	-0.498	4.566
14,776	0.397	$38,117	$34,944	$35,151	0.71	1.24	0.88	-0.6%	($207)	*	4.170	-0.401	4.543
15,276	0.476	$36,522	$33,482	$33,662	0.71	1.19	0.84	-0.5%	($181)	*	4.184	-0.322	4.525
15,776	0.556	$35,226	$32,293	$32,449	0.71	1.15	0.81	-0.5%	($156)	*	4.198	-0.255	4.509

16,276	0.635	$34,140	$31,298	$31,429	0.71	1.11	0.79	-0.4%	($131)	*	4.212	-0.197	4.496
16,776	0.714	$33,210	$30,446	$30,563	0.71	1.08	0.77	-0.4%	($107)	*	4.225	-0.146	4.484
17,276	0.794	$32,399	$29,702	$29,788	0.71	1.06	0.75	-0.3%	($86)	*	4.237	-0.100	4.473
17,776	0.873	$31,683	$29,046	$29,110	0.71	1.03	0.73	-0.2%	($64)	*	4.250	-0.059	4.463
18,276	0.952	$31,043	$28,460	$28,503	0.71	1.01	0.71	-0.2%	($45)	*	4.262	-0.021	4.454
19,521	0.198	$46,959	$42,119	$40,884	0.70	1.45	1.02	2.9%	$1,235	*	4.291	-0.704	4.624
19,776	0.238	$44,952	$40,319	$39,145	0.70	1.39	0.98	2.9%	$1,175	*	4.296	-0.623	4.606
20,276	0.317	$42,020	$37,689	$36,597	0.70	1.30	0.92	2.9%	$1,092	*	4.307	-0.498	4.576
20,776	0.397	$39,878	$35,768	$34,730	0.70	1.24	0.87	2.9%	$1,039	*	4.318	-0.401	4.553
21,276	0.476	$38,209	$34,271	$33,270	0.70	1.19	0.83	2.9%	$1,001	*	4.328	-0.322	4.535
21,776	0.556	$36,863	$33,055	$32,080	0.70	1.16	0.80	2.9%	$975	*	4.338	-0.256	4.519
22,276	0.635	$35,717	$32,036	$31,082	0.70	1.11	0.78	3.0%	$954	*	4.348	-0.197	4.506
22,390	0.653	$35,482	$31,826	$30,875	0.70	1.10	0.77	3.0%	$960	*	4.350	-0.185	4.503

* QA normalized by dividing by the maximum economic rate, 6,300.

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HELLFIRE II
MAXIMUM YEARLY QUANTITY

year	annual qty	X cum qty	propose unit cost (Esc$)	propose unit cost (FY93c$)	lot cost	Y cum average price (FY93c$)	regress (FY93c$)	delta	*	log(X)	log(Y)
		1					$39,694		*	0.000	
FY93	5,976	5,976	$31,799	$30,459	$182,021,862	$30,459	$30,221	$237	*	3.776	4.484
FY94	6,300	12,276	$29,742	$27,877	$175,625,269	$29,134	$29,547	($413)	*	4.089	4.464
FY95	6,000	18,276	$31,044	$28,460	$170,759,076	$28,913	$29,181	($268)	*	4.262	4.461
FY96	4,114	22,390	$35,482	$31,825	$130,929,185	$29,448	$28,995	$452	*	4.350	4.469

Regression Output:

Constant	4.598722	$39,694
Std Err of Y Est	0.007422	
R Squared	0.631481	
No. of Observations	4	
Degrees of Freedom	2	

X Coefficient(s) -0.031354353 slope 97.85%
Std Err of Coef. 0.0169368148

HELLFIRE II
MINIMUM YEARLY QUANTITY

year	annual qty	X cum qty	propose unit cost (Esc$)	propose unit cost (FY93c$)	lot cost	Y cum average price (FY93c$)	regress (FY93c$)	delta	*	log(X)	log(Y)
		1					$42,492		*	0.000	
FY93	1,747	1,747	$43,340	$41,513	$72,523,927	$41,513	$41,417	$96	*	3.242	4.618
FY94	1,245	2,992	43,498	$40,770	$50,759,218	$41,204	$41,341	($137)	*	3.476	4.615
FY95	1,245	4,237	44,886	$41,150	$51,231,271	$41,188	$41,292	($103)	*	3.627	4.615
FY96	1,245	5,482	46,959	$42,119	$52,438,743	$41,400	$41,255	$145	*	3.739	4.617

Regression Output:

Constant	4.628309	$42,492
Std Err of Y Est	0.001813	
R Squared	0.198725	
No. of Observations	4	
Degrees of Freedom	2	

X Coefficient(s) -0.003431930 slope 99.76%
Std Err of Coef. 0.0048728927

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HELLFIRE II

YEARLY PRODUCTION QUANTITY	R squared
2,000	0.92
4,000	0.90
maximum	0.63
minimum	0.20
2,000 in odd years and 4,000 in even years	0.88
maximum in odd years and minimum in even years	0.00

Learning and Production Rate in Cost Estimating

Theme Topic

Innovative Estimating Techniques for Business Base Changes & Related Overhead Impacts

Abstract

Production rate is a very important factor in estimating manufacturing costs. Actual price data shows that production rate has a much greater affect on cost than learning. Hellfire missile price data shows that the production rate slope is 85% and the learning slope is 98%.

Cost analysts frequently use learning as the only variable in creating cost estimating relationships from historical data bases for manufacturing costs. Predicting future costs due to changes in annual and cumulative production quantities should use both learning and production rate to prevent erroneous cost estimates. Large errors in predicting cost and quantities can result due to ignoring rate.

When production rate is considerable less than Maximum Economic Rate, which is frequent in U S Army weapon systems production, then production rate should be a factor in manufacturing cost estimates. High production rate lowers unit cost, and vice versa low production rate increases unit production cost. By quantifying the production rate factor and learning factor, we can spend the taxpayer's money more wisely and plan smarter procurement strategies.

How Subject Relates to Theme

Lower production rate is a frequent reaction to cutting current costs, but this usually results in a higher unit production cost due to the government and contractor's fixed costs or business base. Production rate is shown to have a much greater impact than learning in manufacturing cost estimating relationships and unit production costs.

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SHORT PERSONAL BIOGRAPHY - Alan Markell

Alan has a Bachelor of science degree with a major in mathematics and a minor in physics from the University of Southern Mississippi, a master of science degree in geophysics from the University of Houston, a certificate in petroleum land management from the Oklahoma City Community College. Alan worked 15 years in oil and gas exploration prior to beginning work for the U S Army.

Alan began his Operations Research Analyst career 5 and one half years ago. Alan worked in the Directorate for Systems and Cost Analysis for three years at the U S Army Aviation Systems Command (AVSCOM) now called ATCOM in Saint Louis, Missouri (from 1/88 through 3/91).

Alan has worked in the Cost Analysis Branch of Air-to-Ground Missile Systems Project Office at Redstone Arsenal Alabama for the last 2.5 years (from 3/91 though the present 9/93).

Alan has a wife and two young children.

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PERSONAL:

age:	46	excellent health
height:	5' 8"	married, 2 children
weight:	170	

EDUCATION:

B S 1971 University of Southern Mississippi
major: mathematics minor: physics

M S 1977 University of Houston
major: geophysics

C M 1982 Oklahoma City Community College
major: petroleum land management

EXPERIENCE:

9/86-present U S Department of Defense, operations research analyst

10/83- 9/86 Markell Oil Company, Oklahoma City, OK
Geophysical consulting. Economic evaluation of "distress sale" oil and gas wells and recommend bid, negotiate joint ventures, try to collect accounts receivable.

5/77-10/83 oil companies, Oklahoma City, OK
Geophysical interpretation with recommendation, such as, lease land, drill, do not drill, farm out, acquire more information, plan and recommend geophysical petroleum exploration programs, solicit bids for exploration programs, quality control seismic acquisition, quality control seismic and gravity computer processing, determine availability, sources, and quality of geophysical data.

9/71-12/75 Seismograph Service Corp, Tulsa, OK
Supervisor of scientific computer data processing center (5 men), party chief of seismic crew (25 men), supervisor of two seismic crews (50 men)