Observation of Production Rate Effect in Historical Weapon Systems Cost

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Abstract

Production rate effect has been repeatedly observed in historical cost data for Department of Defense electronics and weapons systems during the the procurement phase of the acquisition lifecycle. This paper will illustrate these real life observations of production rate effect when purchasing end items from major defense contractors.

Background

Cost estimators regularly apply the principle of learning curves to estimate the change in costs of an item over successive production lots. Learning curve theory applies when sufficient quantities are manufactured in each production lot, the configuration of the items do not significantly change over the course of the production run, and the workforce is stable during production. Assuming these conditions are met, unit learning curve theory holds that the cost required to produce a unit decreases a fixed amount with each doubling of the cumulative production quantity.[1] The familiar formula used to estimate these costs is:

$$y = Ax^{b} \tag{1}$$

where for unit learning curve theory:
y is the cost of the production lot being estimated;
A is the cost of the first theoretical production unit;
x is the midpoint of the production lot being estimated; and
b is the learning curve slope ($\frac{\ln(learning\ curve)}{\ln 2}$).

Learning curve theory classically impacts direct labor hours, but also affects direct material and other associated costs. The logic for this is that a significant portion of prime contractor material costs, at least for Department of Defense (DoD) electronics and weapons systems, is actually subcontractor or vendor labor required to create finished items. These finished items are sold to the prime contractor and subsequently reported as direct material costs.

Less frequently used in cost estimating, but nonetheless a potentially powerful cost phenomenon, is the impact of production rate effect (PRE), whereby manufacturing additional units within a production lot results in a reduction of unit cost. The impact of PRE on production lots is in addition to the learning curve effects.

Rate effect functions in a manner similar to a learning curve in that it exists in logarithmic space, resulting in defined unit price decreases with the doubling of lot quantity. PRE differs from learning curves in that it lacks “memory”, only affecting the unit costs of the specific lot being estimated. The impact of PRE within one production lot does not carry over to the next. First proposed by RAND in 1974, PRE is expressed as an extension of the unit learning curve formula by the equation:[2]

$$y = Ax^{b}q^{r} \tag{2}$$

where for PRE theory:

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[1] SCEA Cost Estimating Body of Knowledge, Module 7: Learning Curve, slide 6.

[2] Ibid, slide 75.

y, A, x and b are the same terms from the unit learning curve equation (1) above;
q is the quantity of the production lot being estimated; and
r is the PRE slope ($\frac{\ln(rate\ effect)}{\ln 2}$).

Practically speaking, the cost impact of production PRE can be quite significant on modern DoD electronics and weapons systems produced in large quantities, as will be discussed.

For the purposes of this paper, PRE is defined as the unit cost reduction of direct material obtained exclusively through quantity variation within a single production lot. That is, when looking at the cost of a single production lot, and ignoring the effects of the learning curve, what is the impact on the unit material cost as a result of altering the lot quantity?

The Source of Production Rate Effect

At first exposure, rate effect can seem a little puzzling. In the commercial marketplace, especially with less expensive items sold through traditional retail means, the unit cost remains the same regardless of how many items are purchased. However, this logic does not hold for the procurement of DoD systems. The central concept underlying rate effect is the presence of significant fixed costs in the manufacture of finished items. As mentioned above, for DoD electronics and weapons systems, most direct material costs are finished items from suppliers which are then integrated by the prime contractor into functioning end items. These finished items require for their delivery to the prime the full range of manufacturing costs, including: recurring material; touch and support labor for fabrication and assembly; systems engineering and program management support (SE/PM); and fee, general and administrative (G&A), cost of money (COM), and overhead. The categories of material and labor, as well as the burdening of those elements, are customarily viewed as being variable costs, while SE/PM, is usually treated as largely fixed. Overhead costs are typically a combination of fixed and variable costs. If one accepts that view of how variable and fixed costs are segregated, by definition the fixed costs will remain the same regardless of quantity manufactured. As quantities increase, the fixed costs will be amortized over an increasingly larger base, which ultimately reduces unit costs.

Direct Material and Production Rate Effect

Direct material are those costs assigned and reported in the contractor's accounting system as being specifically charged in support of a single contract, as distinct from indirect material costs, which generally are allocated to multiple contracts.[3] Direct material is the most elemental of costs available to a cost estimator, and excludes all contractor burdening applied to the final sell price, such as overhead, G&A, COM and fee. Direct material is also one of the three principal categories of direct costs, along with direct labor and other direct costs.

The phenomena of unit cost reductions associated with increasing quantities can be observed in a variety of situations, such as with contract negotiated prices or overall program budgets. However, for

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[3] Federal Acquisition Regulations, Sections 31.202 and 31.203.

the purposes of this paper, the concept of PRE is defined as applying only to direct recurring material costs. For the manufacture of most electronics and weapons systems, the majority of the system unit cost is attributed to direct recurring material costs, so due to its significance this is considered to be a worthy cost element to examine.

Effect on Unit Price of Large Lot Quantities

At more aggressive, i.e. lower magnitude, PRE slopes, the impact on unit prices of large production quantities in a single year can be quite surprising to analysts whose primary experience lies with traditional learning curves. In particular, the production of munitions and missiles can often exceed 100 units a year, and with those high quantities the full impacts of production rate effect can be observed.

To take a straightforward example, imagine a munitions program just entering into production with a T1 cost of $100k. The production profile of this hypothetical system is as follows:

Table 1. Procurement Quantities by Lot

Lot	LRIP 1	LRIP 2	FRP 1	FRP 2	FRP 3	FRP 4
Quantity	10	25	50	100	200	200

LRIP and FRP are abbreviations for the lots of Low Rate Initial Production and Full Rate Production, respectively.

To simplify the discussion, imagine the munition does not experience learning on either its labor hours or material costs; and that at a system level, the prime mission product (PMP) experiences a composite 90 % PRE.

To calculate the average unit cost of the first lot, by referring back to formula (2), $y = Ax^b q^r$, the x^b term goes to unity since this system experiences no learning.[4] Therefore, the formula in this example reduced to:

$$y = Aq^r. \tag{3}$$

Substituting in for the parameter in Equation 3 from the given information, the average unit cost for LRIP 1 is:

$$y = (\ \$100k\ )\ (10)^{\frac{\ln 0.9}{\ln 2}} = (\ \$100k\ )\ (10)^{-0.152} = (\ \$100k\ )\ 0.705$$
$$= \$70.5k$$

This is a substantial discount from the first unit, almost 30 %, due to attaining over three doublings of quantity (2-4-8).

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[4] Recall b is (ln (rate effect) / ln 2). When the rate effect is 100 % or 1, its natural logarithm is zero, causing the b term to reduce to zero. Any base term x with a 0 exponent reduces to a value of 1.

Applying the quantities of the subsequent lots to Equation 3 yields the following results:

Table 2. Average Unit Cost by Lot

Lot	LRIP 1	LRIP 2	FRP 1	FRP 2	FRP 3	FRP 4
Quantity	10	25	50	100	200	200
Unit Cost ($K)	$70.5	$61.3	$55.2	$49.7	$44.7	$44.7

Note that with a quantity of 50, the unit cost drops to a little more than half of the T1 value, and with a quantity of 100, the unit cost falls to just under half of T1. If learning were also taken into account, unit costs would drop even lower. The results are graphically shown below in Figure 1.

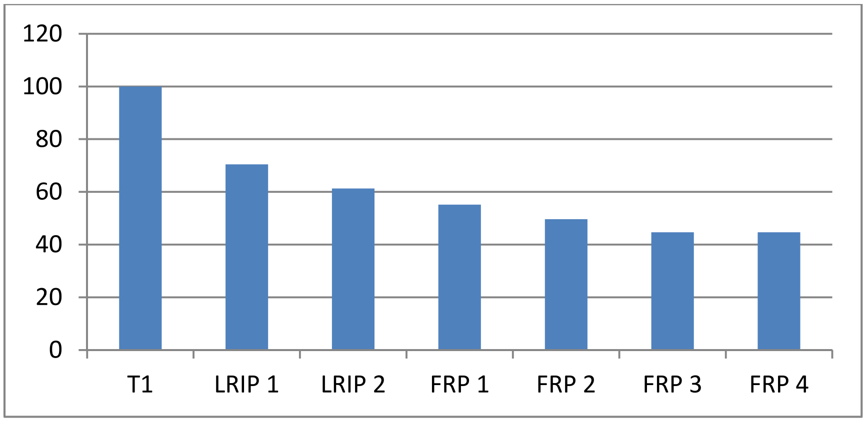


Figure 1. Average Unit Cost by Lot

Methodology

Although the specific methodology for calculating PRE will vary between data sets, it is vital to first thoroughly examine the data to ensure the appropriate costs are analyzed. For this study, basic examination of the data was used to determine the most appropriate regression analysis for each program, either univariate for PRE in insolation, or multivariate for systems where both PRE and learning curves were apparent. The Excel add-in CO$TAT, part of the Automated Cost Estimating Integrated Tool (ACEIT) suite, was used to perform regression analyses. All results were assessed for significance and validity of each regression using standard statistical tests such as R^2, adjusted-R^2, T-Statistic, F-Statistic and examination of the standard residuals plot.

Data Collection and Normalization

Data collection in support of PRE analysis will vary depending on a number of factors, particularly the stage in a program's life cycle at which a cost estimate is being performed. For programs early in the life cycle, typically Milestone A and Milestone B estimates, the data collection should focus on contractor actual costs of analogous systems. For programs at Milestone C or later, data collection should focus on contractor actual costs expended for that program. In both cases, collecting actual costs will result in the most accurate analysis and estimates and should always be pursued by analysts. The two primary sources for actual material costs for DoD electronics and weapons systems are CCDRs and PBOMs collected directly from the prime contractor and any major subcontractor, if available.

It is important for cost analysts to be aware of the differences between planned costs and actual costs when collecting data to analyze historical rate effect. Contactor proposals will often include PBOMs with costs based on vendor quotes, purchase agreements, or even the contractor's own estimate. Basing a PRE analysis on planned PBOM costs can be inaccurate, as contractor actual costs are often considerably different from planned costs due to factors including additional negotiation with vendors after contract award, expiration of quotes or purchase agreements, and changes in the quantity of material items being procured.

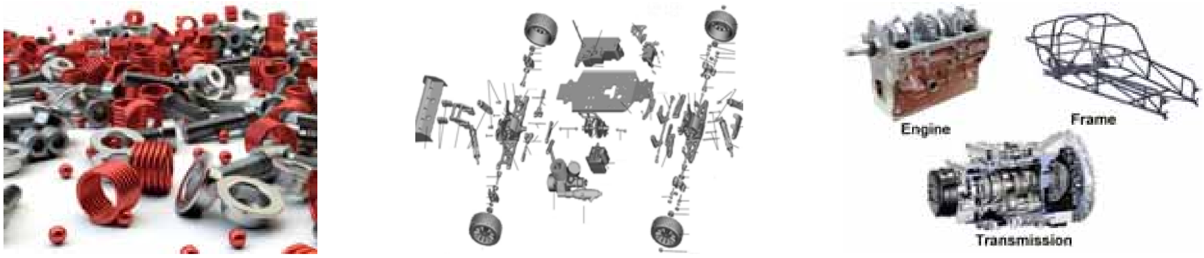
When developing an estimate based on the program's actual costs, the best data source to collect in order to analyze PRE is PBOMs from low–rate initial production (LRIP). PBOMs should contain actual contractor information, including costs, for all recurring parts, components, and subassemblies associated with the manufacture of an electronics or weapons system. Each of these material types have a direct cost associated with them, and it is important to understand the distinction between each.

Parts are items which, when joined together with another item are not normally subject to disassembly without destruction or impairment of use.
[5]

Components are items which have physical characteristics of relatively simple hardware items and which are listed in the specifications for an assembly, sub-assembly, or end item.[5]

Subassemblies are self-contained units of an assembly that can be removed, replaced, and repaired separately.[5]

Below is a graphical depiction of the categories of material that would be used to build a Humvee or automobile.[5]



Parts **Components** **Subassemblies**

Figure 2. Examples of Material Categories

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[5] Federal Acquisition Regulations, Sections 31.205-26(a).

In order to validate PBOMs as being representation of actual costs, a cost analyst should evaluate the items comprising the top 80 % of the total system cost. For a weapons system, this can be up to 50 items, or 5 % to 10 % of the number of items in the PBOM. The cost analyst should confirm the PBOM prices represent actual costs by requesting invoices that would be used to validate the actual unit cost in the PBOM.

The data analyzed in this study were collected in support of a number of different estimates and include both CCDRs and PBOMs. Once collected, all data were normalized prior to performing any analysis. As with data collection, the process for data normalization will be different for each data set but will usually include some common processes.

Ensuring all costs are in a constant year is necessary before performing any analysis. The PBOMs in this study were received in then year dollars and converted to constant year dollars using standard Office of the Secretary of Defense (OSD) escalation indices. The CCDRs were assumed to be in the then year dollars of the midpoint of the effort and also escalated to a constant year across all reports using OSD escalation.

In addition to escalation, several of the data sets needed to be normalized for quantity inconsistency. For CCDRs, lower-level WBS quantities are not always consistent with the total system quantity within or between production lots. Additional quantities of subassemblies or components will sometimes be procured within the prime mission product WBS element for component-level tests or other uses. If the ratio of subassembly quantities to total system quantity is not consistent between lots, the AUCs of the lots should not be compared. In order to normalize for these quantity differences, the AUCs for all subassemblies were independently calculated and then summed to get a consistent system-level AUC for all lots.

PBOMs can also reflect the same quantity inconsistency as CCDRs and if PRE analysis will be performed on the system-level AUC, the same normalization should occur. Additionally, material costs reported in PBOMs are typically reported by order number for each part. Within a given lot, the same part can be purchased on more than one order and will therefore have more than one entry in the PBOM. It is not uncommon for different orders of a single part within one lot to have different unit prices. Since the definition of rate effect used for this study refers only to quantity differences between lots, any instances of rate effect within a single lot due to different order quantities were not analyzed. In order to normalize these cost differences, the total cost of each part number was divided by the total quantity for that part to calculate a lot-representative AUCs.

There are many other potential normalizations that may need to be addressed for a specific data set prior to performing an analysis for PRE. Additional examples are given in the sample analyses presented below. Visual examination of the data sets was used to identify outliers in the data that required further analysis. Outliers were often found to be the result of data abnormalities such as accounting differences between lots, quantity discrepancies, or reporting errors that could be mitigated through appropriate normalization. Outliers for which no identifiable root cause was determined were not excluded from the analysis.

Analysis

Once the data were appropriately normalized, the basic approach for PRE analysis was to perform a regression analysis using CO$TAT software based on the equations discussed previously. The appropriate model equation was determined independently for each data set. Programs for which only three lots of data were available were analyzed only for rate effect. Ideally, data sets should have more than three observations to maintain the degrees of freedom for regression analysis, however actual production costs are often very limited, particularly for programs approaching Milestone C or full rate production. For programs with a larger number of observations, the AUC was plotted against both lot midpoint and quantity to determine which independent variable correlations were apparent. In most cases, multivariate regression for both learning curve and rate effect was performed for programs with a high number of observations.

Two examples of program-specific analyses are given below to demonstrate the analytical process used to determine PRE. One analysis was completed in support of a Milestone B estimate for a missile system and is based on PBOM data. Another was completed in support of a Milestone B estimate for an electronics system and is based on CCDR data for an analogous system.

Sample PBOM Analysis – Missile System A

Missile System A was a multinational development effort and had several countries participating in its development, including the United States. Missile System A was a prior variant for a new missile system approaching Milestone B. The development plan for the new missile called for a redesign of the front end of the missile, but an identical aft end as Missile System A. This design continuity allowed for analysis of actual data from the prior variant.

To perform the analysis, PBOMs for three production lots were collected from the prime contractor. Analysts also requested invoices, purchase orders, and purchase agreements for the major cost drives in order to validate the PBOM costs as actuals. The costs in these supporting documents matched those in the PBOMs and thus the PBOM data were verified as actual costs.

One of the biggest challenges prior to performing analysis on the data was dealing with inclusion of multiple international vendors and normalizing the material costs of the subassemblies. The material prices were provided either in pre-converted United States dollars (USD) or in the currency of the supplier. This required an extra step of normalization to convert all costs to USD, which necessitated working with the prime contractor to understand the appropriate foreign exchange rates for different years. After the costs were normalized into a constant year USD, the PBOMs were analyzed at the part level to appropriately bucket costs into the major subassemblies.

Initially, a visual analysis was performed on the AUCs of the subassemblies by lot. A few of the AUCs for subassemblies did not pass visual inspection, and these subassemblies were therefore excluded from the analysis. For the rocket motor, control fins and the harness cable, PRE was apparent, as seen in Figure 3.

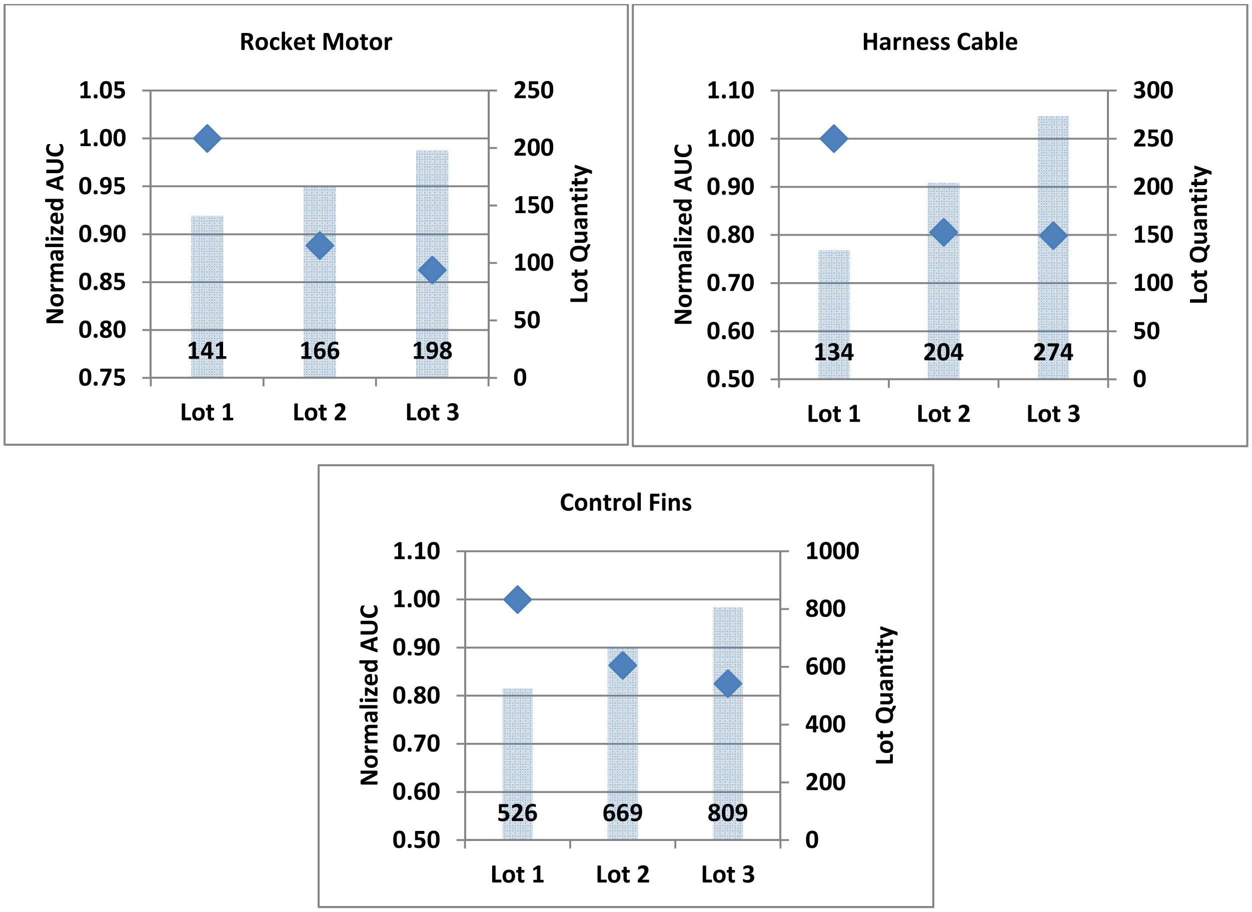

Figure 3. Subassembly AUCs by Lot

The results of the regression analyses performed on all three subassemblies are summarized in Table 3.

Table 3. Results of Regression Analysis on Subassemblies of Missile System A

Subassembly	PRE Slope	R^2 Adj	T-Stat: Prob Not Zero Ind. Var.	F-Stat: Prob Not Zero Reg	Residual Distribution
Rocket Motor	74.1 %	75.4 %	77.2 %	77.2 %	Normal
Harness Cable	79.7 %	71.3 %	75.3 %	75.3 %	Normal
Control Fins	73.0 %	89.6 %	85.3 %	85.3 %	Normal

The PRE demonstrated by the subassemblies of Missile System A is substantial and serves to illustrate the major impact PRE can have on the cost of DoD systems. All of the statistical tests produced values which exceed thresholds generally accepted as minimum requirements when evaluating the validity of a regression analysis. While several of the statistical values fall on the lower end of the “acceptable” range, the analysis was used in support of the Milestone B estimate. To account for the lack of any statistically-dominant result, all of the results were used to create an uncertainty distribution for PRE which was applied to the material costs for all LRIP and FRP lots.

Sample CCDR Analysis

Radar System A was analyzed as an analogy, along with several other DoD systems, in support of a Milestone B cost estimate for an electronic warfare (EW) system. The system for which the estimate was being developed had no prior variants, so the analysis relied heavily on analogous systems for many inputs, including expected PRE slopes. In support of the estimate, production data was collected in the form of CCDRs for the analogous systems, including Radar System A. For Radar System A, 1921 Cost Data Summary Reports (CSDRs) and 1921-1 Functional Cost-Hour Reports (FCHR) were available for seven lots of data: LRIP lots 1-4 and FRP lots 1-3.

Since production material and labor costs were being estimated independently, the analysts analyzed the historical data at the same level, extracting isolated material and labor costs from the data reports. For material costs, the “Total Material Dollars” reporting line was pulled from the PMP element 1921-1 report. Total quantities were also pulled from the report in order to analyze costs at the unit level.

Material costs and system quantities were extracted for each of the seven production lots. CCDRs report costs as actual expenditures, meaning the data often represent a summation of several then year dollars. In order to normalize the data, the midpoint of each report was assumed as the base year for purposes of applying escalation and normalizing all costs to a constant year. Figure 4 shows the average unit material cost and quantity procured for each lot.

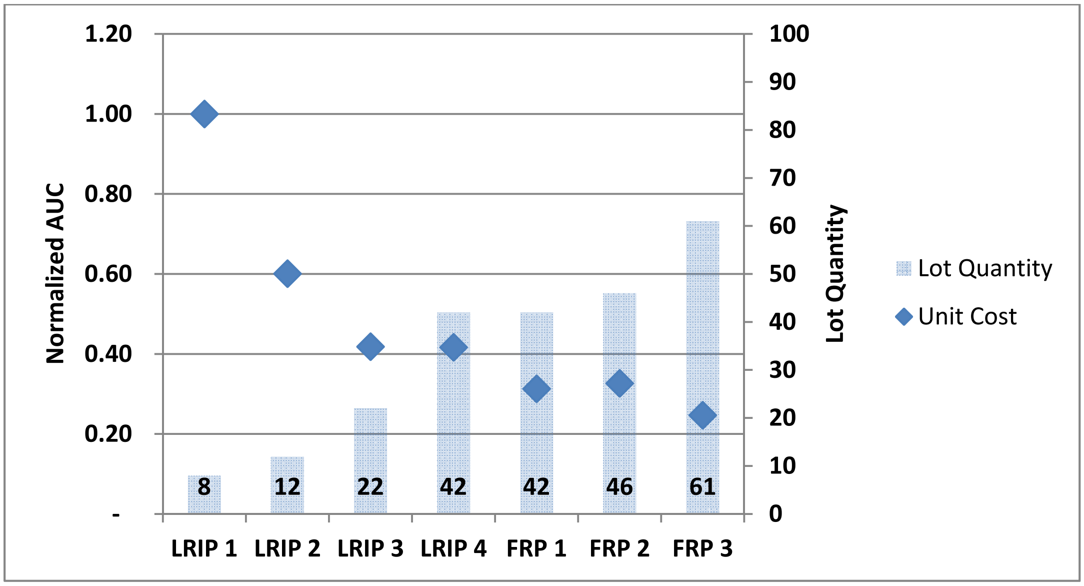

Figure 4. Radar System A Unit Material Cost and Procurement Quantity by Lot

Initial inspection of the data shown in Figure 4 suggested the presence of both PRE and material learning. The presence of PRE is generally supported by the noticeable decrease in unit cost between FRP 2 and FRP 3 when the system is sufficiently "down the learning curve," but there is a increase in lot quantity. The presence of learning is generally supported by the decrease in unit cost between LRIP 4 and FRP 1, which have a consistent quantity. Also of interest is the 40 % decrease in unit cost between LRIP 1 and LRIP 2, which is a drastic cost reduction considering the relatively low number of units produced in each lot.

CO$TAT was used to perform a multivariate regression to determine the PRE and learning curve slopes. The analysis returned a PRE slope of 92.4 % and a learning slope of 84.1 %, and demonstrated strong fit statistics, including an adjusted R^2 of 93.8 %. However, it was also clear that the large cost decrease between LRIP 1 and LRIP 2, which propagated to later lots, was significantly impacting the analysis. Upon further inspection, this trend was not apparent at the total recurring PMP cost level, as shown in Figure 5.

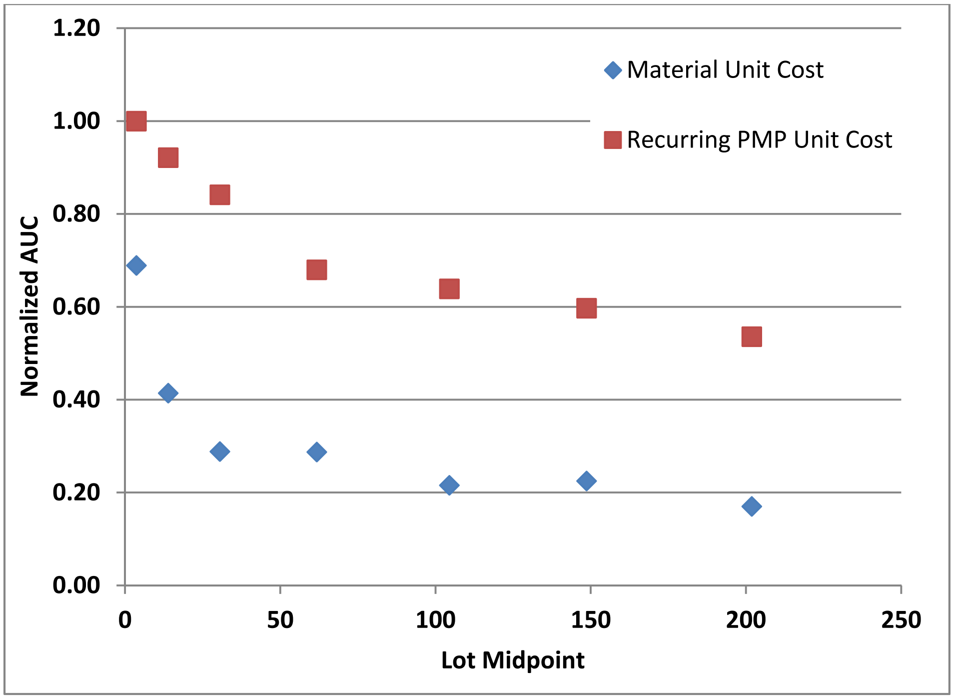

Figure 5. Material and Total PMP Average Unit Costs by Lot

Based on Figure 5, it was clear that material costs for LRIP 1 contributed a much larger portion, 69 %, of total recurring PMP cost than for any subsequent lot, where the maximum contribution of material costs was 45 %. This discrepancy suggested that there was likely a variation in the reporting of material costs between lots which required additional investigation and normalization.

The 1921-1 reports provided enough information into detailed costs to determine the major contributors to the total PMP unit cost other than material. For LRIP 1, the remaining costs could be attributed to labor, ODC, and fringe costs. For all other lots, at least 30 % of the total recurring PMP cost was bucketed in the “Other Costs Not Shown Elsewhere” line of the 1921-1 report. Fortunately, reporting guidelines require that these costs be described elsewhere on the report and in the case of this system, at least 75 % of these “Other” costs were described as being intra-organizational transfer (IOT). IOT costs are for materials that the prime contractor “purchases” from other business units of the same company. These costs cannot be included with the standard material costs from vendors because prime contractors are not allowed to apply burdening to IOT material. For the sake of this analysis, the IOT material needed to be treated as equivalent to the material purchased from vendors. Once these additional costs were included in the unit material cost calculations, Figure 4 was updated with the correct material unit costs, shown in Figure 6.

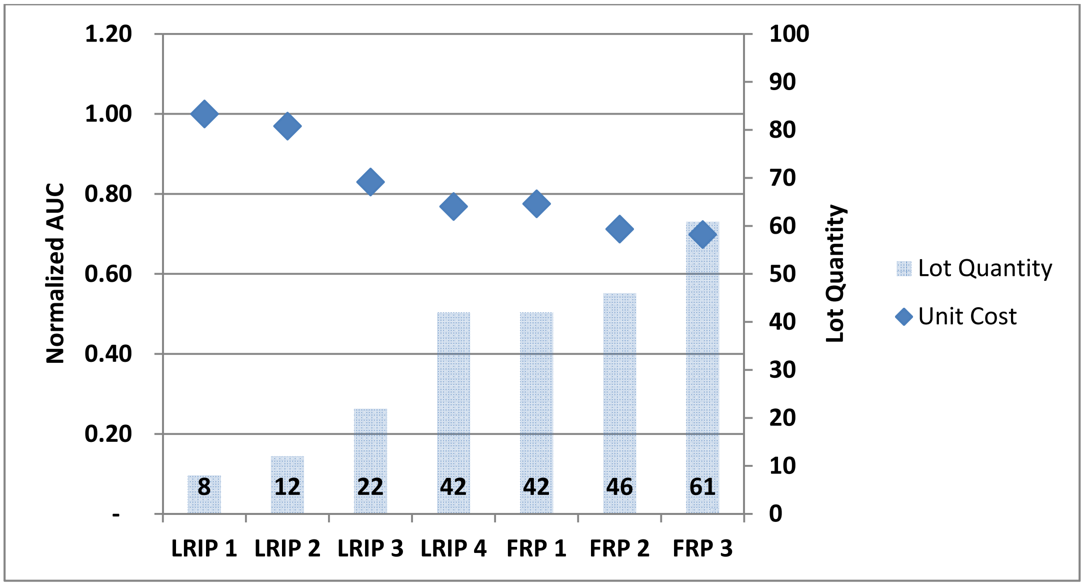

Figure 6. Radar System A Corrected Unit Material Cost and Procurement Quantity by Lot

The updated data set was analyzed using the same multivariate regression in CO$TAT, which returned a PRE slope of 92.2 % and a learning curve slope of 97.7 %. The fit statistics included an adjusted-R^2 of 94.5 %, a probability not zero of the coefficient of the independent variable of 97.1 %, and a probability not zero of the regression of 99.9 % with normally distributed residuals. These statistics are very strong and even represented an improvement over the strong statistics determined from the initial, incorrect regression. The updated analysis resulted in less extreme slopes for both PRE and learning curve compared to the original analysis, and also demonstrated that PRE had a larger impact on material costs than the learning curve.

The results of the analysis on Radar System A data were in line with the results determined from similar analysis performed on other analogous systems, suggesting a defendable trend in historical data. These results were used in the Milestone B estimate for the EW system to estimate material costs for all production lots.

Results

In addition to the analysis presented above, PRE analysis was performed for seven additional systems, either in support of a cost estimate or specifically for this study. The data set includes four radar systems, three missile systems, a rocket launcher, and one unmanned aerial vehicle (UAV). The full results are presented in Table 4. All values for the probability not zero of the coefficient of the independent variables are based on the t-statistic of the lot quantity independent variable for multivariate regressions.

Table 4.

Commodity	Data Source	PRE Slope	Learning Slope	R^2 Adj	T-Stat: Prob Not Zero Ind. Var.	F-Stat: Prob Not Zero Reg	Residual Distribution
Radar A	CCDR	92.2%	97.7%	94.5%	97.1%	99.9%	Normal
Radar B	CCDR	97.8%	99.5%	72.1%	93.1%	86.1%	Normal
Radar C	CCDR	97.9%	95.7%	87.5%	56.5%	97.9%	Normal
Radar D	CCDR	100.4%	96.0%	46.6%	6.1%	57.8%	Normal
Missile A RM	PBOM	74.0%		75.4%	77.2%	77.2%	Normal
Missile A HC	PBOM	73.0%		71.3%	75.3%	75.3%	Normal
Missile A CF	PBOM	80.0%		89.6%	85.3%	85.3%	Normal
Missile B	CCDR	89.4%	97.8%	34.6%	95.1%	93.4%	Normal
Missile C	CCDR	88.9%		76.4%	91.8%	91.8%	Normal
Rocket Launcher A	CCDR	94.5%	98.0%	51.2%	89.7%	95.1%	Normal
UAV A	CCDR	94.5%	88.6%	93.0%	61.2%	99.2%	Normal

The analysis of Radar D resulted in a PRE slope greater than 100 %, along with very poor fit statistics. A root cause analysis ultimately determined an engineering design change resulted in an altered design for two major subassemblies of the system during the middle of production, which rendered the results invalid for use in an estimate. Additionally, the analysis of Missile B and Rocket Launcher A, while producing logical results for PRE and learning curve slopes as well as strong probability not zero values, resulted in adjusted-R^2 values well below the acceptable threshold and were therefore excluded from any further analysis or application. Analysis of UAV A did result in a probability not zero of the independent variable coefficient below the common threshold of 70 %, however it was included in the analysis of the overall dataset due to the strength of the remaining statistics and logical analysis results. All other data points were deemed acceptable, with adjusted-R^2 and probability not zero values over 70%.

PRE values for all systems, excluding those eliminated from analysis, range from a minimum of 73.0 % to a maximum of 97.9 %, with a median value of 90.7 %. Of the eleven data points, seven were analyzed using multivariate regression in conjunction with a learning curve and four were analyzed for PRE in isolation. It is possible that performing regression analysis for PRE in isolation artificially decreases the resulting slope, as the median value for those four data points is 76.9 % while the remaining data points analyzed with multivariate regression have a median of 96.2 %. However, all univariate regression analysis was performed on missile systems and therefore this inconsistency could be the result of other factors, detailed below.

In general, the missile systems demonstrated more extreme PRE slopes, with a median PRE slope of 76.9% compared to a median PRE slope of 96.2 % for all other systems. This could suggest that the impact of PRE is greater on systems produced in larger quantities. The missile systems in these results were all procured in lots averaging over 100 units while the radars, rocket launcher, and UAV systems were all procured in lots averaging fewer than 50 units.

Also of note are the values for PRE calculated from Missile A data, which have a median value of 74.0 %, which is almost 20 % lower than the median value for the total data set. This could be a result of several factors. First, Missile A was procured in lot quantities greater than those even for the other two missile systems, and could be further evidence of the increased in impact of PRE on systems produced in greater quantities. In addition, Missile A was analyzed at the subassembly level, while the remaining systems were all analyzed at the total system level. The best method of analysis depends on the intended use of the results in a cost estimate, but these results suggest there may be a noticeable difference between subassembly-level PRE and system-level PRE. This could result from increased negotiation between the prime and vendors for the primary cost drivers, a lack of PRE on system parts used for system integration versus as part of a larger subassembly which world lessen the impact of PRE at the total system level, or an unknown cause. Finally, Missile A was the only system for which data taken from prime contractor PBOMs were analyzed, suggesting a potential cost accounting discrepancy between contractors' internal accounting systems and the submitted CCDRs. Additional analysis would be required to further explore these theories.

Conclusion

Although not as universally applied to cost estimates as learning curves, PRE can be a significant cost driver and should be considered by cost analysts when appropriate. PRE has been repeatedly observed in actual cost data for historical DoD weapons and electronics systems, with a data set comprised of nine systems resulting in a median PRE of 92.2 %. The primary data sources to support the analysis of PRE are CCDRs and PBOMs collected from contractors. Actual cost data present unique issues for normalization and need to be critically analyzed to ensure a good foundation for performing analysis. Equally as important as proper normalization is ensuring that results of analysis are applied appropriately as part of a cost estimate, accurately representing the data on which the methodology is based.

In addition to merely demonstrating the prevalence of PRE in DoD systems, the analysis for this effort provided some lower-level insight into PRE that could be further analyzed to enhance the understanding of PRE and how it impacts DoD systems. The results suggest that the impact of PRE is greater for systems procured at higher average lot quantities, such as missiles and munitions. Analysis also suggested that subassembly-level costs may be subject to higher levels of PRE than total system-level costs. Finally, the results demonstrate a possibility that more aggressive PRE slopes are observed in

PBOM cost data than CCDR cost data. This could be further explored by collecting both PBOM and CCDR data for a single system and comparing the results. The collection of additional data for the systems analyzed in this paper, as well as others, would provide the opportunity for further analysis into PRE and its impacts on DoD systems. It would also allow analysts a chance to explore some of the theories proposed in this study.