Estimating Support Labor for a Production Program

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ABSTRACT

Common methods for estimating support labor are; Percent to Touch Labor, Fixed / Variable, Semi-Variable, and Improvement Curves. The problem with improvement curves is that rate variation may require an adjustment. The problem with the other methods is that they do not significantly address variation due to program maturity. Variation in support labor due to program maturity is usually different than the variation in touch labor due to program maturity. In other words, support labor does not follow the same improvement slope as touch labor.

Support Labor costs to a production program are a function of two things:

1. Experience (or Maturity)
   – As a program matures, you typically need less support
2. Production Quantity (or Rate)
   – Higher production rates require more support (but typically a lower proportion)
   – Lower production rates require less support (but typically a higher proportion)

This model uses Experience and an adjusted formula for Production Quantity as the two predictor variables to predict the dependent variable which is the support labor hours per year.

- Experience is a number which is as a combination of years and cum quantity.
- Production Quantity is adjusted to get a number that represents the "Degree of Difficulty" in producing that quantity.

Regression analysis was performed of support labor hours against the two predictor variables and achieved high correlation. The resultant formula looks like this:

Support Hours = a - b · (Year · Cum Quantity)$^{\wedge 0.5}$ + c · Qty $^{\wedge\,(1\,/\,\mathrm{Year}\,\wedge\,0.5)}$

This formula is used in estimating similar production programs with adjustments for programmatic differences.

The methodology is applicable to almost any industry, from aerospace to zippers. This paper describes how to set up your historical data, perform regression analysis, and calibrate the model to create an estimate for your production program.

Introduction

Support Labor are the people who perform necessary work, but not directly hands on to the product. For example; Manufacturing Support, Quality, Tooling Support, Material Support, Engineering Support, Business and Program Management Support.

Common methodologies to estimate support labor are:

1. Percent (Ratio) to Factory Touch Labor
2. A Function of Fixed and Variable
3. A Semi-Variable (Power) Function
4. Improvement Curve

Methodology 1 – **Percent (Ratio) to Factory Touch Labor** (Y = bX):
where b is the Slope (the Percent) and X is Touch Labor

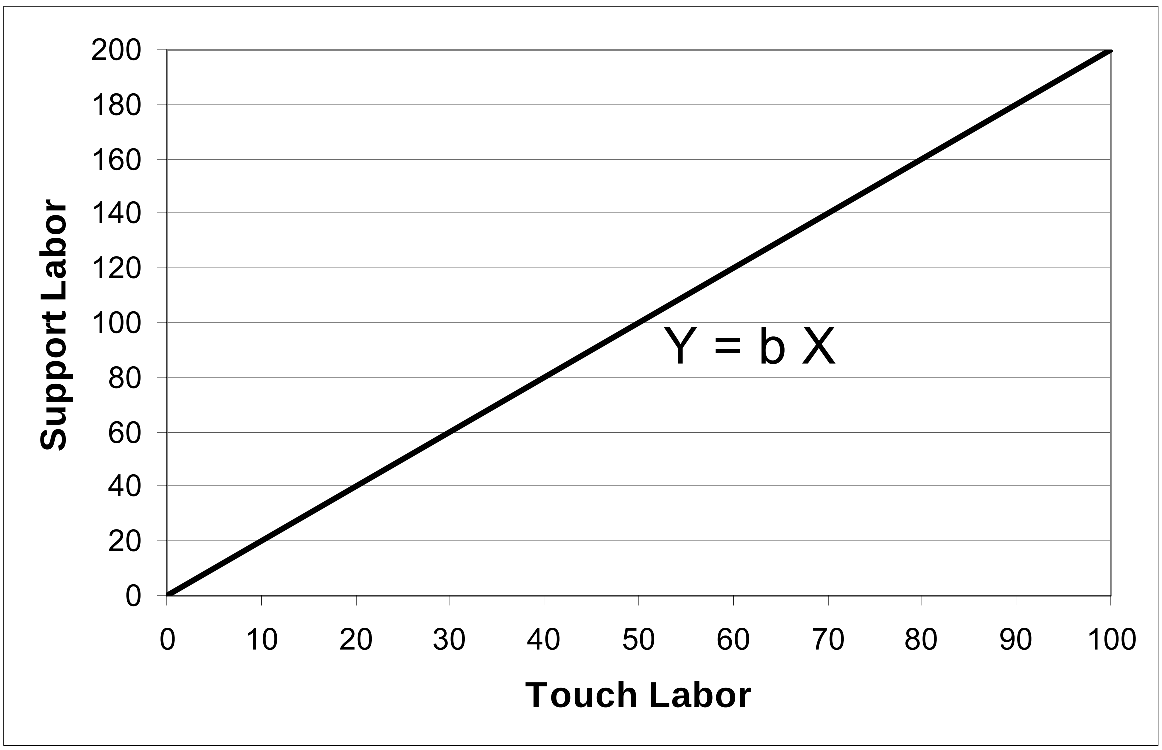

Figure 1: Straight Line – Percent to Factory

The problem with this methodology is that it assumes that support labor is the same ratio to touch labor for any production rate and for any time throughout the maturity of the program. In practice, at lower production rates, support labor does not get smaller at the same rate. In other words, the line will not go straight towards the origin. Also, improvement from learning is not the same for support labor as it is for touch labor, so the ratio of support labor to touch labor changes as a program matures. There is often more improvement for support labor, so the ratio of support labor to touch labor (the slope b) decreases as a program matures.

Methodology 2 – **A Function of Fixed and Variable** (Y = a + bX):
where a is the Fixed Part (the Y Intercept)
and bX is the Variable Part, b is the Slope (variable amount per unit)
X is the Production Rate (or it could be Touch Labor).

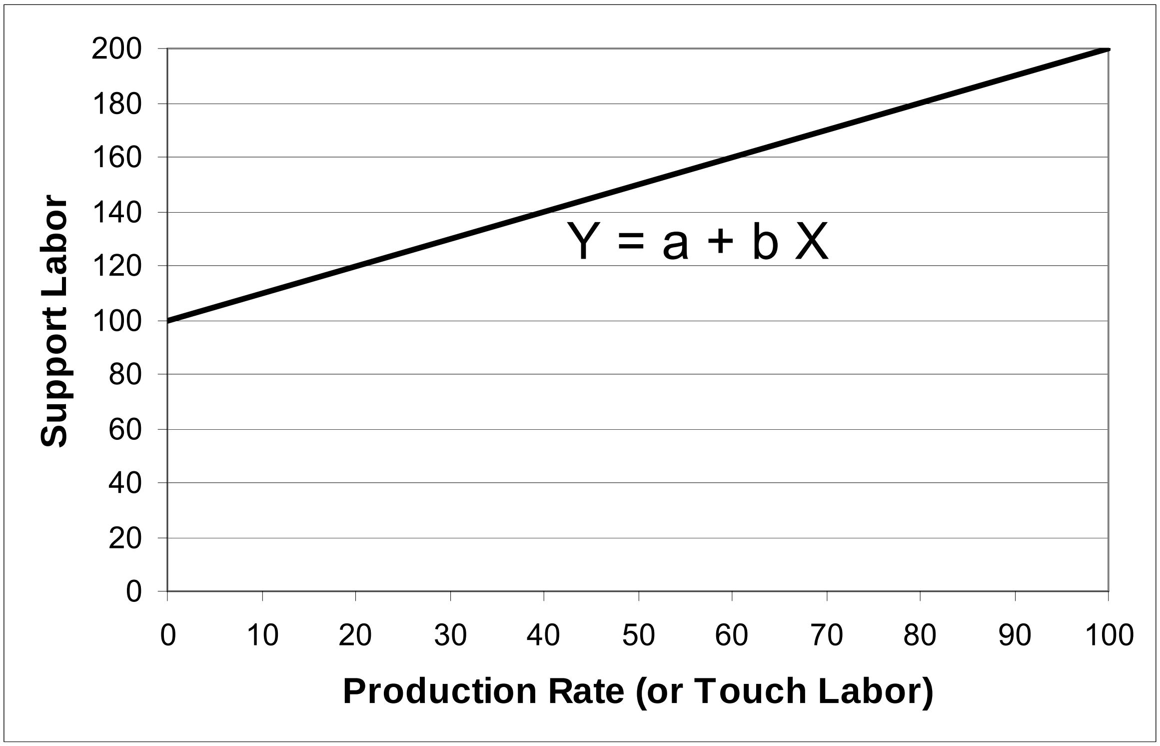

Figure 2: Straight Line – Fixed and Variable

In practice, this approach has two problems:

- The "fixed" part (a) isn't really fixed. It goes down as the program matures. Think of the "fixed" part as the amount of support labor you would need if there was only one unit in production. Suppose you stayed at that production rate for a long time. Obviously, the "fixed" amount would go down over time. So the "fixed" part has variability due to program maturity. As a program matures, you typically need less support, all else being equal.
- The "variable" part (bX) has more variability than is predicted by production rate (or touch labor) alone. The "variable" part is the amount of support you need over the "fixed" part to support the production rate. The maturity of the program needs to be considered, in addition to the production rate, because it is more difficult (requires more support labor) to produce a small number of units in the early years of production than it is to produce a large number of units in a mature program. The "variable" part generally goes down as the program matures.

Methodology 3 – **A Semi-Variable (Power) Function** ($Y = aX^{\wedge b}$):
where a can be thought of as the "Fixed" Part (the value when production rate is 1) and b is the "Logarithmic Slope". X is the Production Rate (or it could be Touch Labor). For example, as shown below, when the production rate is halved, support can be reduced by 25%.

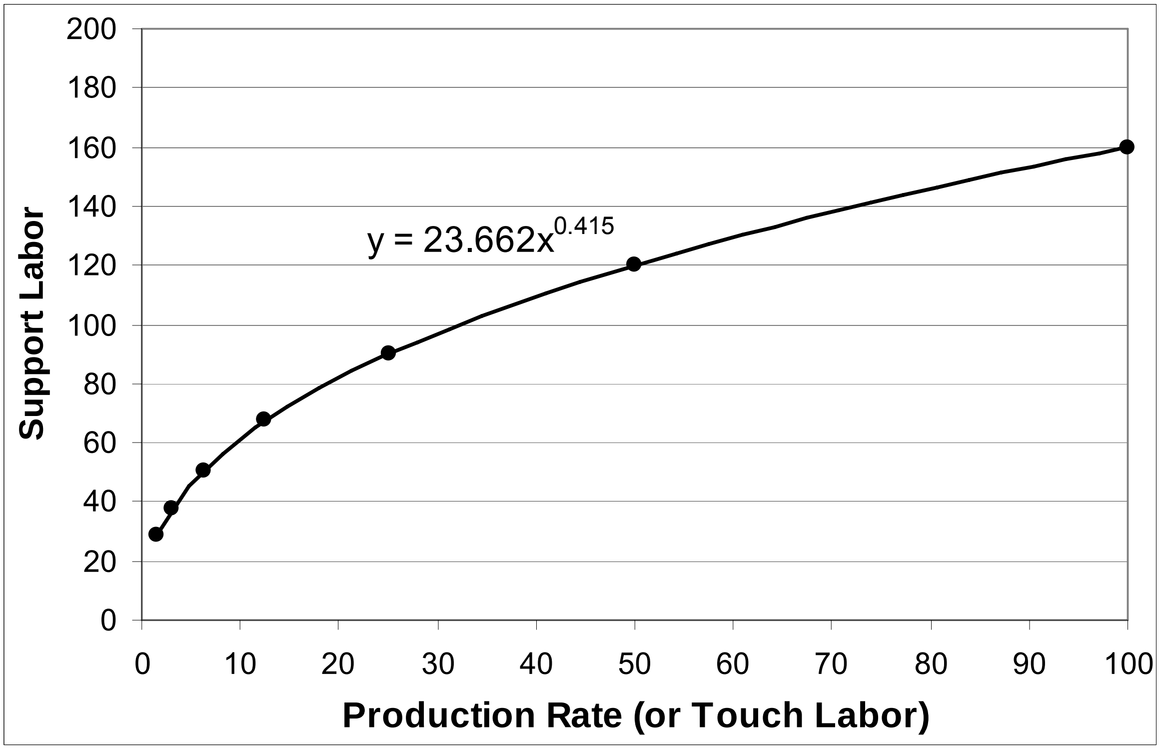

Figure 3: Semi-Variable (Power) Function

In practice, this approach has two problems:

- As in the previous example, the "fixed" part (a) isn't really fixed. It goes down as the program matures.
- As in the previous example, the "variable" part has more variability than is predicted by production rate (or touch labor) alone. The maturity of the program needs to be considered, in addition to the production rate. The "variable" part generally goes down as the program matures.

Methodology 4 – **Improvement Curve** ($Y = aX^{\wedge b}$):
The hours per unit continually improve at a logarithmically decreasing rate.
Y is Support Labor Hours per Unit, X is the Cum Unit Number, a is the T1 Value (the hours for the first production unit), b is the Log of the "Slope" divided by Log (2).
Note: The improvement curve "Slope" = 10 ^ (b • Log(2))
or if you are using natural logarithms, the "Slope" = Exp (b • Ln(2))
For example, as shown below, the notional "Slope" is 70%, which means that every time the cumulative quantity doubles, there is a 30% improvement in hours per unit.

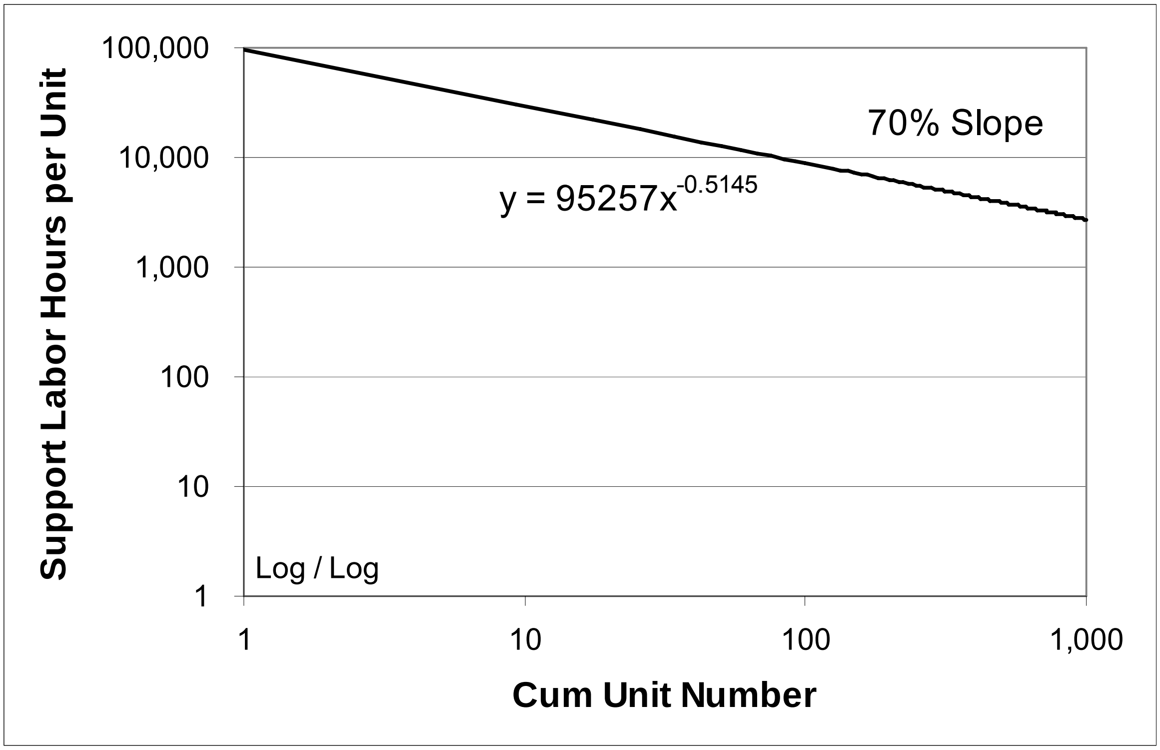

Figure 4: Semi-Variable (Power) Function

The problem with using an improvement curve for support labor is that the hours per unit come down the curve without regard to rate. If there is a significant change in rate, the support labor hours per unit will deviate from the line because the total support labor required will not vary in the same proportion as the rate change.

- Higher production rates will require some additional support, but not in proportion to the rate increase, so the hours per unit will deviate below the line.
- Lower production rates will require less support, but not in proportion to the rate decrease, so the hours per unit will deviate above the line. For example, if the production rate was cut in half, you could not cut the support labor by half.

You can try to adjust for this effect by using an augmented improvement curve or by subtracting a fixed number of hours from the total and only applying the improvement curve to the remaining "variable" hours.

The problems with Fixed / Variable and Semi-Variable methodologies is that the "fixed" part isn't really fixed and the "variable" part has more variability than is predicted by production rate alone. Both the "fixed" part and the "variable" need to include the dependency on the maturity of the program. To correct these problems, we could develop different equations (with ever decreasing intercepts and slopes) each year as the program matures. Using a fixed / variable methodology, the resulting equations might look like this.

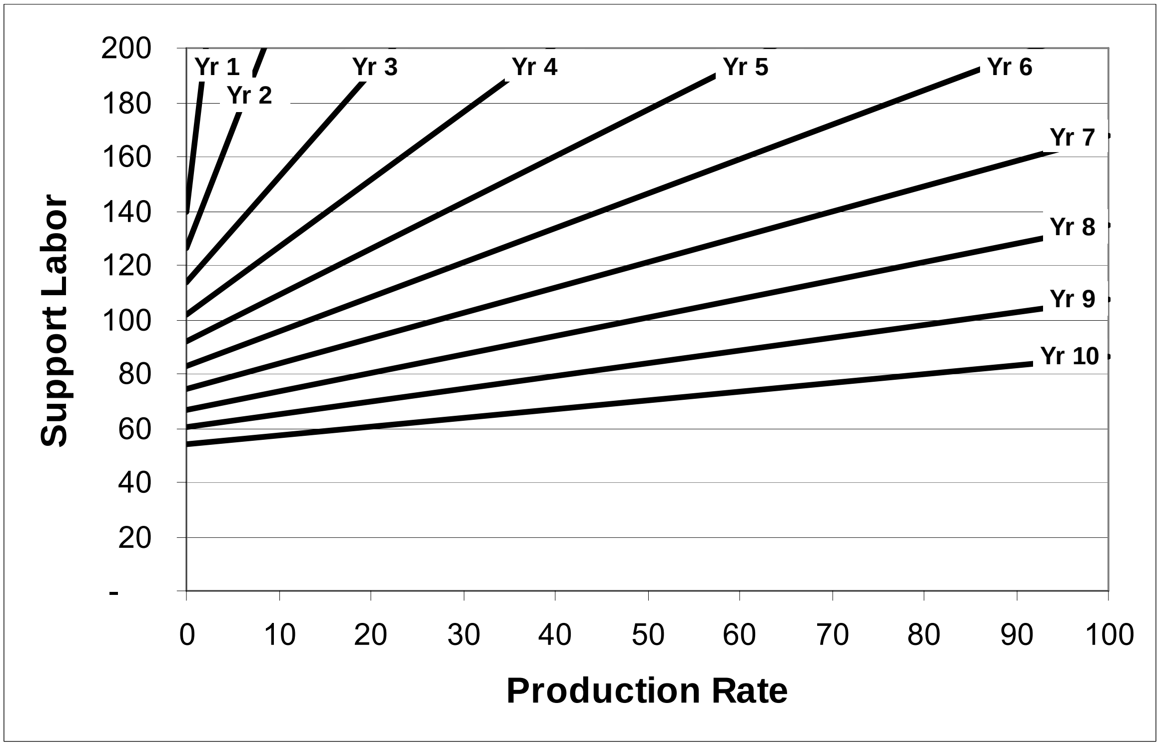

Figure 5: Fixed / Variable With Ever Decreasing Intercepts and Slopes

Using a semi-variable methodology, the resulting equations might look like this.

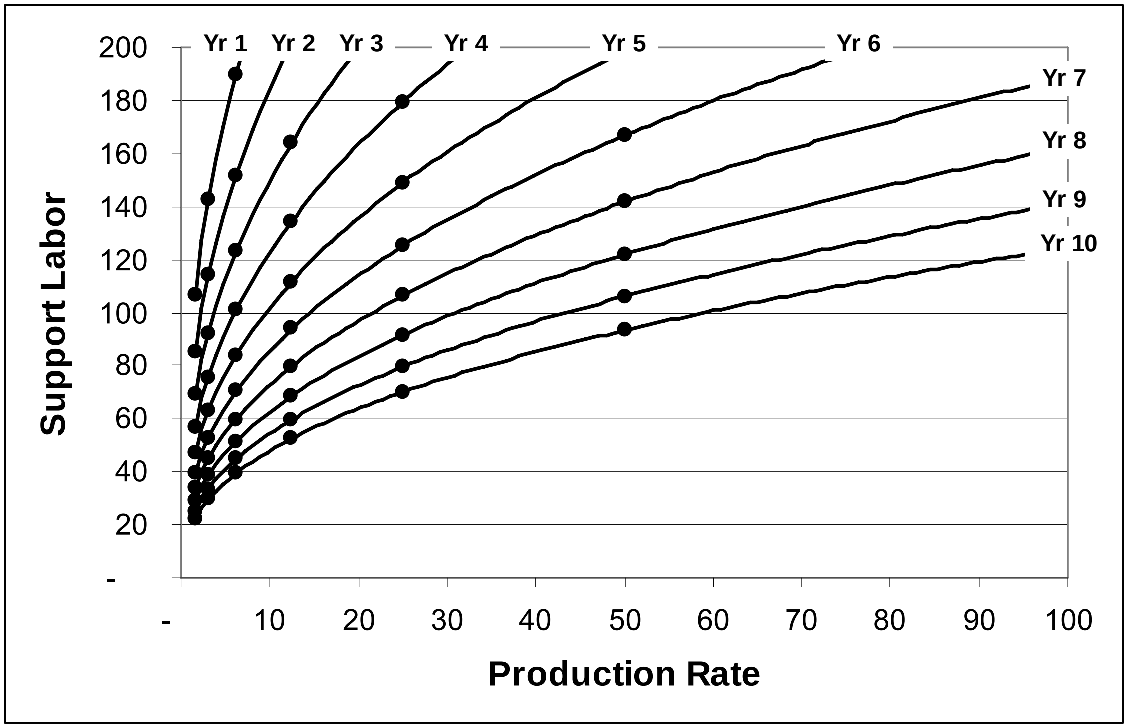

Figure 6: Semi-Variable With Ever Decreasing Intercepts and Slopes

Model Development

It would not be practical to use a different formula every year and it would be difficult to calculate the formulas for all those lines.

Using regression analysis, a single equation was developed to estimate annual support labor hours. Regression was performed of support labor hours against two predictor variables for 18 years of production history.

The first predictor variable is a measure of program maturity or “Experience”. What is Experience? Is it an amount of time (years, months) or is it the number of units that have been produced to date? In this model, Experience is a number which is a combination of years and cumulative quantity. Just multiply the two numbers together and take the square root:

Experience = (“Year” x “Cum Quantity”)$^{\wedge\ 0.5}$

“Year” is a value of 1 for the first year of production and goes up 1 per year to the end of production. “Cum Quantity” is the total number of units that have been produced (to the midpoint of each year).

The second predictor variable is a measure of the “degree of difficulty” in producing the annual production quantity relative to the maturity of the program.

Production Degree of Difficulty = “Quantity”$^{\wedge\ (1\ /\ \text{Year}\ \wedge\ 0.5)}$

“Quantity” is the annual production quantity and “Year” is as described above.

Here is a sample data table used to perform regression analysis.

First Predictor Variable

Second Predictor Variable

Dependent Variable

Year	Annual Quantity	Midpoint Cum Unit	SQRT (Yr·Midpt)	$1/Yr^{0.5}$ Qty^	Support Hours
1	6	3.5	1.87	6.00	460,000
2	10	11.5	4.80	5.09	408,000
3	7	20.0	7.75	3.08	338,000
4	20	33.5	11.58	4.47	381,000
5	58	72.5	19.04	6.15	415,000
6	96	149.5	29.95	6.45	397,000
7	96	245.5	41.45	5.61	379,000
8	136	361.5	53.78	5.68	370,000
9	139	499.0	67.01	5.18	358,000
10	140	638.5	79.91	4.77	324,000
11	123	770.0	92.03	4.27	292,000
12	99	881.0	102.82	3.77	277,000
13	94	977.5	112.73	3.53	290,000
14	84	1,066.5	122.19	3.27	276,000
15	73	1,145.0	131.05	3.03	239,000
16	52	1,207.5	139.00	2.69	215,000
17	42	1,254.5	146.04	2.48	240,000
18	56	1,303.5	153.18	2.58	240,000

Figure 7: Data Table - Sample Historical Data

The last few years of production history (years 19 and up) have been excluded, because when program termination is near, changes are minimized and some support labor functions are reduced at a significantly greater rate than would be predicted by the trend up to that point. You should consider doing the same if this phenomena occurs in your industry. Then, if you use the model to estimate out to the very end of production, you need to adjust the last few years to account for this effect.

Here are the regression results.

REGRESSION SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9780612
R Square	$\boxed{0.9566037}$
Adjusted R Square	0.9508175
Standard Error	16007.123
Observations	18

ANOVA	df	SS	MS	F	Significance F
Regression	2	8.5.E+10	4.2E+10	165.326	6.038E-11
Residual	15	3.8.E+09	2.6E+08		
Total	17	8.9.E+10			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	284,201.0	26,349	10.7862	1.8E-08	228040.38	340361.58
X_1 Variable	(813.96)	111	-7.32623	2.5E-06	-1050.771	-577.1529
X_2 Variable	23,754.1	4,467	5.31712	8.6E-05	14231.876	33276.244

Figure 8: Regression Results

Regression results show a coefficient of correlation, R, of .978, and a coefficient of determination, R^2, of .956, with significant t Stats for each variable. Your results may vary. Based on the regression, the predicted hours for each year are calculated as follows.

$$\text{Hours} = 284{,}201 - 814 \cdot (\text{Year} \cdot \text{Cum Qty})^{0.5} + 23{,}754 \cdot \text{Quantity}^{(1 / \text{Year}^{0.5})}$$

This equation is used to estimate other production programs by plugging in the projected production quantities. Adjustments for program differences must be made. Also, you may want to modify the formulas for the predictor variables to obtain better regression results. For example the exponents in the equations do not have to be 0.5. You can try other numbers from 0.3 to 0.7 and see what you get.

Also, beware of the following:
This model was developed in an aerospace environment, but the theory is applicable to many industries. If applying this to larger scale production (rivets, for example) it is recommended that you express the Quantity and Cum Quantity in hundreds or thousands or millions or whatever gets you a value such that Quantity values are no more than 2-digit numbers and Cum Quantity values are no more than 3-digit numbers. Also, you may want to use months instead of years.

Adjustments for Program Differences

There will be differences between the program you are estimating and the historic program/programs which was/were used in the regression analysis.

Examples of program differences are:

- Weight of the product
- Complexity of the product
- Difference in materials
- Difference in manufacturing processes
- Technology improvements
- Organization changes
- Prime contractor or subcontractor
- Manned vehicle or unmanned vehicle
- Special Access Program or no special security

A comprehensive factor is derived, which encompasses all the program differences. That factor is multiplied by the regression formula resulting in annual estimated hours for the new program.

The comprehensive factor is derived by considering what the factor would be for each program difference and multiplying them together. Use your own internal data to develop these factors, but here are some ideas on how you might calculate some of the factors:

For weight differences, try applying an advantage formula (typically an 80% curve) such as: $(\text{Weight}_{\text{New}} / \text{Weight}_{\text{Old}})^{\wedge -0.322} \cdot (\text{Weight}_{\text{New}} / \text{Weight}_{\text{Old}})$. For example, if the weight of the new product is 10,000 pounds and the weight of the historic product was 8,450 pounds, the weight factor is $(10{,}000 / 8{,}450)^{\wedge -0.322} \cdot (10{,}000 / 8{,}450) = 1.12$.

For differences in complexity, materials, and manufacturing process, you should consider counting parts, manufacturing steps, standard hours, etc., and applying an advantage formula such as: complexity factor = $(\text{Parts}_{\text{New}} / \text{Parts}_{\text{Old}})^{\wedge -0.322} \cdot (\text{Parts}_{\text{New}} / \text{Parts}_{\text{Old}})$.

Technology improvements can be significant, especially if the historical data is from a program which was developed before computer aided design came into fashion. Improvement is derived from increased accuracy of the engineering, so that fewer changes are required and the parts fit better, and increased automation in the manufacturing process. Improvement of at least 1 percent for each year difference between the historical data and the new program is probably achievable.

Changes in organization need to be considered. Functions are often moved from one organization to another, and sometimes functions are eliminated. Be aware of what functions were in what organization in the historical data compared to the way things are currently organized and apply an adjustment factor if necessary.

Other program differences may be more subjective to estimate, such as prime contractor vs. subcontractor or manned vehicle vs. unmanned vehicle. Use your own internal data or get a consensus of opinion to estimate factors for those types of differences.

So, the formula for the comprehensive Program Adjustment factor is the product of all the individual factors, or $\Pi f = f_0 \cdot f_1 \cdot \ldots \cdot f_n$.

Example: If it is determined that 3 factors are significant; the weight factor is 1.12, the complexity factor is 1.05 and the technology factor is 0.75, then the comprehensive Program Adjustment factor is $\Pi f = 1.12 \cdot 1.05 \cdot 0.75 = 0.882$.

So, to estimate the support hours for the new program, multiply 0.882 times the formula derived from the regression.

Example:

$$\text{Hours} = 0.882 \cdot [284{,}201 - 814 \cdot (\text{Year} \cdot \text{Cum Qty})^{0.5} + 23{,}754 \cdot \text{Quantity}^{(1 / \text{Year}^{0.5})}]$$

Once you get a year or so of actual data on the new production program, you may not need to estimate the program adjustment factor. The factor will just be the ratio of the actual hours to the predicted hours (without the program adjustment factor).

Example:
Year 1 actuals come in at 340,000 hours and 5 units were produced.
The predicted hours (without the program adjustment factor) are

$$\text{Predicted Hours} = 284{,}201 - 814 \cdot (1 \cdot 3)^{0.5} + 23{,}754 \cdot 5^{(1 / 1^{0.5})} = 401{,}561$$

So the new program adjustment factor, based on actuals is 340,000 / 401,561 = 0.847
So the estimate for future years becomes:

$$\text{Hours} = 0.847 \cdot [284{,}201 - 814 \cdot (\text{Year} \cdot \text{Cum Qty})^{0.5} + 23{,}754 \cdot \text{Quantity}^{(1 / \text{Year}^{0.5})}]$$

Here is a table of data to derive an estimate for future years:

First Predictor Variable

Second Predictor Variable

Program Adjustment

Dependent Variable

Year	Annual Quantity	Midpoint Cum Unit	SQRT (Yr·Midpt)	Qty^ 1/Yr$^{0.5}$	Program Adjustment Factor	Estimated Support Hours
1	5	3.0	1.73	5.00		340,000 actual
2	7	9.0	4.24	3.96	0.847	317,445
3	17	21.0	7.94	5.13	0.847	338,527
4	28	43.5	13.19	5.29	0.847	338,087
5	37	76.0	19.49	5.03	0.847	328,423
6	40	114.5	26.21	4.51	0.847	313,358
7	45	157.0	33.15	4.22	0.847	302,678
8	45	202.0	40.20	3.84	0.847	290,292
9	40	244.5	46.91	3.42	0.847	277,184
10	42	285.5	53.43	3.26	0.847	269,484
11	45	329.0	60.16	3.15	0.847	262,641
12	46	374.5	67.04	3.02	0.847	255,259
13	48	421.5	74.02	2.93	0.847	248,555
14	54	472.5	81.33	2.90	0.847	243,071
15	45	522.0	88.49	2.67	0.847	233,472
16	41	565.0	95.08	2.53	0.847	226,077
17	31	601.0	101.08	2.30	0.847	217,301
18	35	634.0	106.83	2.31	0.847	213,577
19	35	669.0	112.74	2.26	0.847	208,470

Figure 9: Data Table - Sample Estimate Using Program Adjustment Factor

Here is a graph showing 2 lines.

- Predicted Support Labor without adjustment for program differences:

$$\text{Hours} = 284{,}201 - 814 \cdot (\text{Year} \cdot \text{Cum Qty})^{0.5} + 23{,}754 \cdot \text{Quantity}^{(1 / \text{Year}^{0.5})}$$

- Actual Support Labor for the 1st year and Estimated Support Labor for the remainder of the program (15.3 % below the predicted line based on 1st year performance):

$$\text{Hours} = 0.847 \cdot [284{,}201 - 814 \cdot (\text{Year} \cdot \text{Cum Qty})^{0.5} + 23{,}754 \cdot \text{Quantity}^{(1 / \text{Year}^{0.5})}]$$

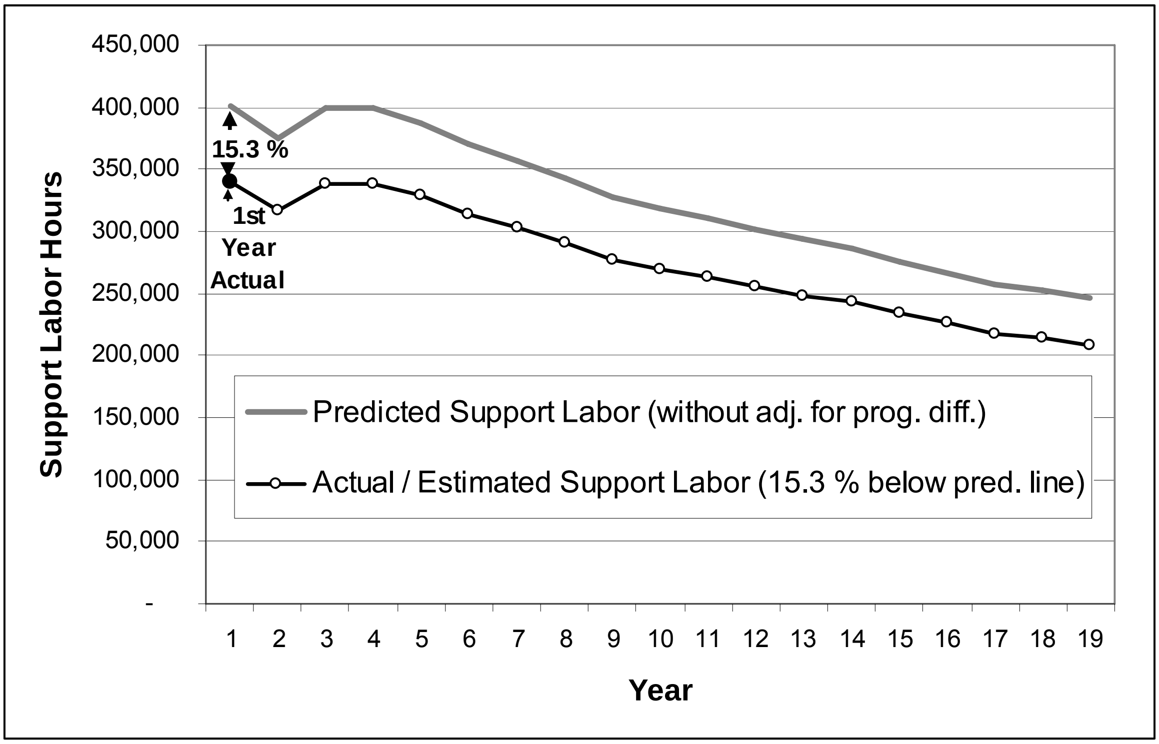

Figure 10: Chart - Estimated Support Labor Hours

Additional Continuous Improvement Adjustment

In estimating future years, you may be able take a more aggressive approach and estimate a line which continually improves against the predicted line, perhaps an additional 1 percent per year. For example, if the gap is 15.3% in the first year, you may be able to achieve 16.3% in the second year, 17.3% in the third year and so on. This is due to continual process improvement, technology improvements, management challenges, etc. which occur to a greater extent in the current environment than they have in the past. How aggressive a line you choose depends on whether the historical programs which were used in the regression were aggressively managed.

Here is a graph showing 2 lines.

- Predicted Support Labor without adjustment for program differences:

Hours = 284,201 - 814 · (Year · Cum Qty) ^ $^{0.5}$ + 23,754 · Quantity ^ $^{(1 / \text{Year} ^ 0.5)}$

- Actual Support Labor for the 1st year and Estimated Support Labor for the remainder of the program with continuous improvement (of 1% per year):

Hours = [0.847 - 0.01 · (Year - 1)] · [284,201 - 814 · (Year · Cum Qty) ^ $^{0.5}$ + 23,754 · Quantity ^ $^{(1 / \text{Year} ^ 0.5)}$]

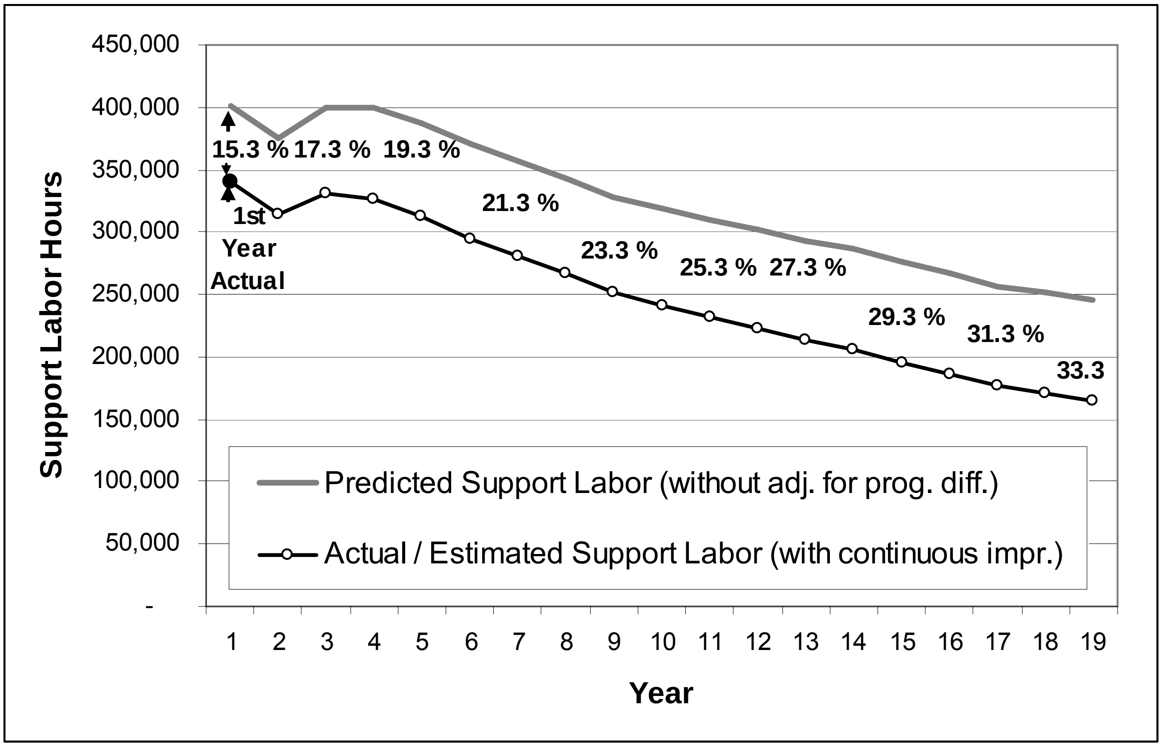

Figure 11: Chart - Estimated Support Labor Hours With Continuous Improvement

Conclusion

Traditional methods for estimating support labor are deficient because they do not correctly model for all sources of variability. This paper outlines a methodology for estimating support labor using regression analysis. This model was developed in an aerospace environment, but the theory is applicable to many industries. It can provide accurate long range estimates. Examples are provided on how to set up your historical data to be able to perform regression analysis to obtain a prediction equation. The formulas can be changed to suit your particular industry. Try changing the exponents in the formulas for the predictor variables to improve correlation. Adjustments for program differences need to be made. Also adjustments for additional continuous improvement should be considered. When actuals start to come in, you can calibrate the performance and see the trend vs. the predicted line.