PREDICTING THE EFFECT OF SCHEDULE ON COST

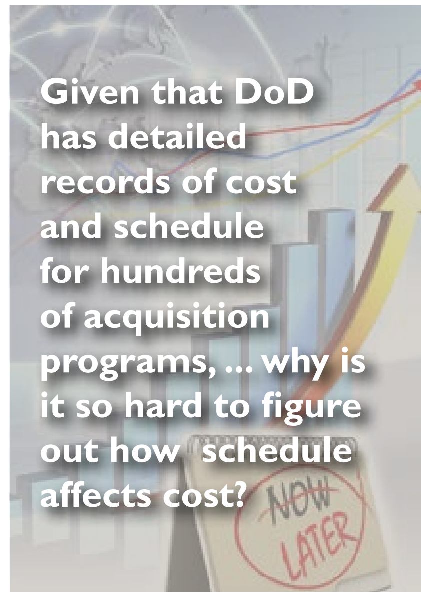
David Tate

The Problem

What is the effect of schedule on weapon system acquisition cost?

WHY DO WE NEED TO KNOW HOW SCHEDULE AFFECTS COST?

In our discussion of the PortOpt model ("Looking Back at PortOpt"), we noted that a key requirement of the PortOpt tool was to be able to predict how the lot costs of a procurement program would change if we were to change the production schedule. This is the fundamental step; if we can't estimate the cost impacts of specific schedule changes, then we can't (1) compare alternatives to the current Selected Acquisition Report (SAR) plans, (2) do sensitivity analysis, and (3) optimize.



WHY IS THIS HARD?

DoD has detailed records of cost and schedule for hundreds of acquisition programs, going back decades. Given that wealth of data, why is it so hard to figure out how schedule affects cost? We believe there are three major analytical obstacles.

OBSTACLE #1: WHICH IS THE CAUSE, AND WHICH IS THE EFFECT?

Consider three procurement programs: A, B, and C. Program A is doing fine, but due to overall budget reductions, A's production schedule is going to be stretched, which will increase unit costs. Program B has just announced significant cost growth—not caused by a schedule change—that has made its planned production schedule no longer affordable. Program C has been experiencing integration issues—its electronics are going to require a new design that uses a more expensive subcomponent, which will have to be retrofitted into existing units. This means both a cost increase (due to the new component) and a schedule slip (to accommodate the new design and the rework).

For all of these programs, unit cost went up and average production rate went down. Causally, though, we have three distinct cases:

- For Program A, schedule stretch caused cost growth.
- For Program B, cost growth caused schedule stretch.
- For Program C, technical issues caused both cost and schedule growth.

We're trying to understand only the first of those mechanisms. Unfortunately, we can't tell just by looking at historical numbers which of those cases was in effect—or whether it was some mix of all of them—for a given program. We need a way to isolate the Program A effect from the others.

OBSTACLE #2: NOT ALL COSTS REACT THE SAME WAY TO SCHEDULE CHANGES

Since 2006, SARs have broken out cost projections into subcategories: end-item recurring flyaway costs, non-end-item recurring flyaway costs, nonrecurring costs, and two categories of support costs. This is very helpful, because we don't expect all of those costs to react identically to a change in production schedule. End-item recurring costs should be most directly affected, while nonrecurring costs and non-spares support might not be affected at all. Our econometric model of how schedule affects cost will have to identify these different cost categories and treat them separately

OBSTACLE #3: LIMITED RELEVANT DATA

If I wanted to understand the relationship between the price of butter today and the price of eggs tomorrow, I could collect a great deal of historical data on butter and egg prices at various times. That would work because the natures of butter and eggs don't change much over time; all of my historical data would describe the same commodities

Acquisition programs, however, are not like that. We can look at the historical SARs for Program A, going back for as many years as Program A has been around—but do those past SARs tell us anything about the relationship today between Program A's production schedule and Program A's lot costs? Since those past SARs were published, Program A may have changed in any number of ways—new designs, revised cost estimates, requirements changes, technology insertions, planned product improvements, new contracts, new demands from the field, for instance.

Unless we could somehow correct for all of the program changes other than schedule, those past forecasts don't tell us what the estimated cost would be today for that prior planned schedule. We generally don't get to see multiple schedules (and their associated costs) for the same exact program. Since we're trying to figure out how cost varies as schedule varies, this is a major limitation.

WHAT WE'VE LEARNED

We have explored a number of competing theories about how and why unit costs change when schedules change. These theories are not necessarily mutually exclusive, which makes it even trickier to figure out how to combine them into a coherent model. Here's what we've learned so far.

FIXED COSTS AND STICKY COSTS

Some of the costs of producing a weapon system are incurred per unit time, rather than per unit produced. For example, the costs associated with running the program office do not depend much on the current production rate, or on how many units have been produced so far. Similarly, the indirect costs associated with contractor overhead are only slightly sensitive to production rates. What's more, overhead rates are "sticky"—they don't generally adjust instantaneously to changes in work level. Our model of how cost depends on schedule will need to be able to distinguish fixed costs from variable costs, and estimate how sticky the fixed costs are.

LEARNING AND FORGETTING

The previous article "Looking Back at PortOpt" also introduced the idea of learning curves. It is not uncommon to see that unit costs seem to follow a standard learning curve for most of the life of a program, but then start to climb upward again toward the end of the program. To account for this, C. Lanier Benkard suggested that producers become more efficient by gaining "experience" making units, but that this experience dissipates at a constant rate.[1] Thus, early in production (when cumulative quantity is doubling frequently), or at high production rates (when more experience is being gained per unit time), learning behavior dominates. Late in the production run, or at low production rates, the gains from learning are visibly offset by forgetting.

We investigated this model, and found that it fits many historical programs quite well. It can also be improved by combining it with a fixed cost model, so that overhead is modeled separately, while direct costs are modeled by a combination of learning and forgetting.

REGULATORY LAG

Finally, William Rogerson has proposed that the interaction between cost progress and production rate can be understood by looking at the incentives inherent in how procurement contracts are awarded.[2] In general, a new fixed-price procurement contract is awarded for each lot, with a price based on the contractor's demonstrated historical costs. If a contractor invests in management or tooling changes that reduce production costs, they will only realize extra profits from this until a new price is negotiated—typically two or three years later.

At high production rates, contractors have more incentive to reduce production costs, because they will realize extra profits on many units during the two- to three-year "regulatory lag" period before the price is renegotiated downward to reflect the lower production costs. There is also a wider range of worthwhile cost-reducing investments available, given the need to make back the initial investment costs through higher profits.

Conversely, at lower production rates the contractor has less incentive to reduce costs, as well as fewer available cost-reduction alternatives that will provide the necessary return on investment. If this theory is correct, we should expect to see less learning

1 C. Lanier Benkard, "Learning and Forgetting: the Dynamics of Aircraft Production," *American Economic Review 90*, no. 4 (Sep 2000): 1034–1054.

2 William P. Rogerson, "Economic Incentives and the Defense Procurement Process," *Journal of Economic Perspectives* 8, no. 4 (Fall 1994): 65–90.

at low production rates, and more learning at higher production rates. This is very different from traditional procurement models, which all assume that the learning curve slope is an intrinsic characteristic of the system being produced.

We can combine this model with a fixed-cost model, as we did with the learning-and-forgetting model. In theory, we could add forgetting to this model as well, but we will generally not have enough data to distinguish between regulatory lag effects and forgetting effects if both are present.

GOING FORWARD

IDA continues to develop and refine models of how schedule changes affect cost. Our investigations suggest that the most useful models for practical applications will combine a fixed-cost model with either a learning-and-forgetting model or a regulatory lag model, depending on the available data and type of system being procured. The model parameters will be fit at the system-type level (e.g., a single value for all helicopters, or all tactical missiles) where possible, and at the program level where necessary.

Estimating cost changes from schedule changes is complicated, and difficult—but necessary. The new models being developed will enable important new capabilities for affordability analysis, portfolio planning, analyzing proposed multi-year procurement contracts, and a variety of other activities important for DoD acquisition planning.

Dr. Tate is a Research Staff Member in IDA's Cost Analysis and Research Division. He holds a doctorate in operations research from Cornell University.

References

Benkard, C. Lanier. "Learning and Forgetting: the Dynamics of Aircraft Production." *American Economic Review* 90, no. 4 (Sep 2000): 1034–1054.

Rogerson, William P. "Economic Incentives and the Defense Procurement Process." *Journal of Economic Perspectives* 8, no. 4 (Fall 1994): 65–90.