

How Green Was My Labor: The Cost Impacts of Manufacturing Personnel Changes

Brent M. Johnstone

Abstract: Estimators are frequently confronted with manufacturing personnel increases or decreases and asked to calculate shop performance impacts. However, existing learning curve literature offers little guidance how to do so. This paper identifies issues associated with both new hires (so-called "green labor") and workforce reductions and offers an analytical format. Based on a study of a large workforce expansion on a mature aircraft program, a model to analyze future personnel changes is presented as well as example cases.

Introduction

In the ideal world of theoretical learning curves, product configurations, production rates and the quantity and skill level of employees remain constant throughout time, thus allowing us to plot smooth, continuous reductions in unit cost over time. In the real world, this is far from the case. All three variables – configuration, production rates, and employees – are in constant flux.

The impact of configuration changes on the learning curve and on manufacturing unit costs are well-understood. The impact of production rates on unit cost has also been extensively studied, albeit with contradictory opinions whether changes in production rates have significant or insignificant long-run impacts on manufacturing hours. (Johnstone, 2017.) However, the published learning curve literature is largely silent on how changes in the number or skill level of manufacturing employees affect cost. While this issue impacts all long-cycle manufacturing operations, typically the literature only addresses the subject in the context of production gaps and the subsequent loss of learning. (Anderlohr, 1969.) However, the impact of production gaps is so deleterious that planners and schedulers go out of their way to avoid them,

and therefore they occur only infrequently. Far more common are increases or decreases in workforce levels due to fluctuations in production deliveries, and yet little is written down to guide the estimator.

This paper hopes to fill in the gaps. Estimators are frequently confronted with workforce increases or decreases and asked to calculate the impacts on shop performance. This paper identifies issues associated with both new hires and workforce reductions and offers an analytical format. Based on a study of a large workforce expansion on a mature aircraft program, a model to analyze future workforce changes is presented as well as an example case.

Overview of the Problem

Questions about workforce changes really ask: What is the impact of assigning new work to people? In turn, assignments of new work are usually driven by changes in delivery rates.

If everyone was equally proficient and skilled – or if the work was simple – this would not be an issue. Manufacturing jobs, however, require a high degree of proficiency and product-specific knowledge which are not easily transferable. This

is particularly acute in the shipbuilding industry. According to industry sources, it takes three to five years for a new hire off the street to be trained and developed into a journeyman employee. It takes an average of eight years to become a fully certified nuclear pipefitter. (Cuccias, 2018.) Estimates of shipbuilding costs require careful consideration of the productivity levels of so-called “green labor” (new hires) and “seasoned labor” (experienced employees). A RAND study on the shipbuilding industry summarizes the issue:

“Workers with some experience are generally more productive than inexperienced workers. Thus, for a workforce with a higher proportion of inexperienced workers, additional effort is needed to complete an identical task. This additional work might be done using temporary workers, overtime, additional full-time employees, or even lengthening the ship production schedule.” (Arena, 2004.)

But this issue is hardly restricted to shipbuilders. The short-term cost impact of hiring new, untrained employees is found in the aerospace industry as well. Commercial aircraft build provides several examples. In the late 1990s, Boeing attempted to significantly increase its 737 and 747 production rates by hiring thousands of new workers. Boeing’s 1997 annual report laments: “In pushing to double production rate to meet heavy demands of a booming market, we experienced serious cost and schedule problems.” (Boeing, 1997.) A front page story from The New York Times that same year describes this further:

“In early October, overwhelmed by thousands of fowl-ups, Boeing temporarily halted production of the 747 as well as the smaller 737....Boeing had to scramble to find people to build its airplanes, hiring 32,000 workers in the last 18 months. Despite what they

describe as an aggressive training program, with five weeks of instruction before starting work, Boeing executives conceded that many new workers were still not fully prepared. ‘We have incurred the penalty of these people learning’ on the job, said Gary R. Scott, the vice president in charge of producing the 737 and 757.” (Zuckermann, 1997.)

Interestingly, Boeing experienced similar issues on the same 747 production line 30 years earlier:

“At the time production was starting on the 747, Boeing could not find enough workers in the Seattle area and was forced to recruit intensively. Of the workers hired, less than half developed into normally productive workers. Labor hours per aircraft increased as production rate and cumulative quantity increased, i.e., the learning curve had a positive instead of a negative slope.” (Large, 1974.)

Yet another case comes from McDonnell Douglas during the same time period, as it struggled to keep up with demand for a stretched DC-8 as well as an increase in DC-9 production. (Large, 1974.)

These impacts are not permanent. Eventually the new employees reach a level of proficiency and their productivity approaches that of experienced employees. But even temporary impacts can create painful damage on production schedules and company profits.

Disruption due to changes in staffing levels is not restricted to new hires brought on to accommodate a production rate increase. Delivery rate *decreases* which result in workforce *reductions* can create similar problems, as we will see. Even maintaining the same number of employees in an area can be problematic, if shop management is forced to reassign roles and responsibilities due to a reduction in another department.

Types of Workforce Changes

As mentioned earlier, there is very little discussion of this potential disruption in learning curve literature. The only text which deals with it at any length is E. B. Cochran’s *Planning Production Costs: Using the Improvement Curve*. (Cochran, 1968.) The first section of this paper draws extensively from Cochran’s exposition.

Suppose a new customer is signed up and delivery rates increase. Small increases in delivery rates can sometimes be satisfied by greater efficiencies in the learning curve as hours per unit decrease over time. However, beyond a certain point, additional employees will need to be hired. There is no change to the aircraft configuration (that would be a design change) but we simply need more bodies to produce the additional aircraft. The consequences are, as Cochran notes:

- Some tasks are continued by workers experienced performing them
- Some tasks are assigned to workers who have no experience performing them
- Some tasks are removed from personnel already performing them for reassignment to either the new workers or members of the original crew

A graphical illustration of a workforce addition due to an increase in production rates is shown in Figure 1. In the current state, it takes a crew of three mechanics to deliver an end-item in seven days. But in order to accommodate a production increase, the production line must be sped up to deliver an end-item in five days. To make that happen, a fourth crew member is added.

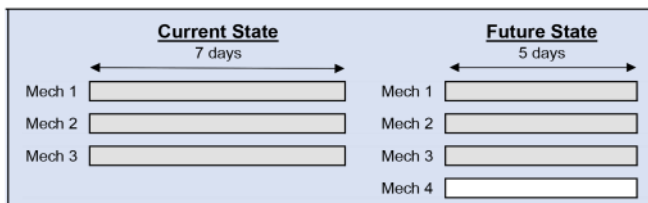


Figure 1. Workforce Addition

This will require work to be reassigned. That reassignment will obviously impact the fourth mechanic, who finds himself doing unfamiliar work. It will also impact the three original crew members. At a minimum, they will have work removed from them. But it is also possible that work will be reassigned among themselves as well.

To express this mathematically, Cochran suggests we use the proportion of new workers added as an index of the tasks which are new to the revised crew. To develop a “new man ratio,” we define p_1 and p_2 as the number of people required before and after the change respectively. For a workforce addition, the “new man ratio” becomes:

$$t_a = (p_2 - p_1) / p_2$$

For a crew of 15, an increase to 20 would mean $t_a = (20 - 15) / 20 = 25\%$. We can interpret t_a as the *minimum* proportion of workers who must perform tasks which are new to them. In this case, at least a quarter of the crew members will have tasks which are new. Due to the reassignment of previous crew workers, the *actual* proportion of workers performing task new to them may be somewhat higher than t_a , but it cannot be less.

Workforce Reduction

Now suppose the delivery rate decreases due to a reduction in customer sales. As deliveries slow and production intervals increase, there is no longer a need for as many mechanics in the shop. To keep costs economical, some will be transferred off the program to perform work on other projects, or perhaps temporarily furloughed or even released by the company altogether.

Many aerospace shops are unionized. The basic agreement between labor and management typically regulates how workforce reductions carried out. In most cases, workforce reductions are carried out by seniority. If a reduction in force is required, the employees with the least experience will be laid off first. This happens

across the entire shop regardless of which program drives the workforce reduction – a reduction in the delivery rate for Program A may drive a layoff of employees in unaffected Program B, if they have less seniority. This potentially creates gaps in crews across the shop floor. As less-senior employees are laid off, the remaining employees are "bumped" into different work areas and sometimes different programs to accomplish the necessary reductions.

There are two major cost impacts of these moves:

- Some employees will have all-new tasks due to being "bumped" into a new area with associated learning loss.
- The remaining employees will have an expanded scope of work as span times increase. Employees must be trained to handle additional scope; a percentage of everyone's work will be new to them.

A graphical illustration of a workforce reduction due to a decrease in production rates is shown in Figure 2. In the current state, we have four crew members working to deliver an end-item every five days. To accommodate the slowdown, we only need three crew members to deliver a product every seven days. The fourth mechanic may be moved to a different area, a different program, or leave the company altogether; but his work will have to be reassigned to the remaining three mechanics, who now find themselves performing tasks with which they are unfamiliar.

Not surprisingly, this necessary realignment of work will create a temporary disruption which

will result in higher hours per unit while personnel become accustomed to their new tasks.

As defined by Cochran, the "new man ratio" for a workforce reduction is:

$$t_d = (p_1 - p_2) / p_1$$

For a crew of 15 which is reduced to 10 mechanics, $t_d = (15 - 10) / 15 = 33\%$. At least one third of the work must be reassigned to mechanics for whom it is new. Note that our denominator is different for a workforce reduction. Whether we are dealing with a workforce increase or decrease, we always measure the change against the larger of the two numbers, p_1 or p_2 .

Turnover

Turnover occurs when a certain number of mechanics are replaced by an equivalent number, but the total workforce count does not change. It frequently occurs as an extension of a workforce decrease. In the previous example, Program A experienced a delivery rate requiring a workforce reduction. Program B continues to build at the same delivery rate as before and requires no change in headcount. But because of the "bumping" of employees across the shop floor, Program B now finds itself with employees who formerly worked on Program A and are unfamiliar with the unique requirements and processes of Program B. This too will create some temporary disruption.

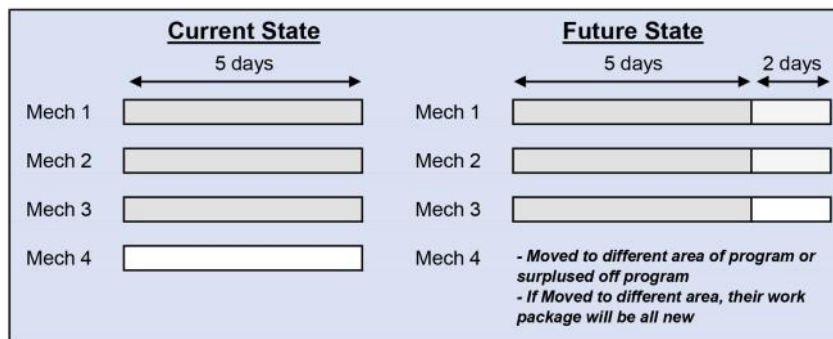


Figure 2. Workforce Reduction

Designating p as the total number of employees and d as the number removed, Cochran defines the "new man ratio" for a task turnover as:

$$t_t = d/p$$

For a crew of 15, assume five mechanics are removed and their places taken by new ones. This yields $t_t = 5/15 = 33\%$. So at least

a third of the mechanics will be performing tasks which are new to them.

Estimating the Impacts of Changes

Calculating the “new man ratio” for a workforce change does not, however, tell us the cost impact of a workforce change. We cannot assume that a 25% “new man ratio” translates to a 25% cost increase. If we think back to Anderlohr’s five elements of learning improvement – production personnel, supervision, continuity of production, tooling, and methods – we can see that only the first and second elements are impacted by a workforce change. (Anderlohr, 1969.) Assuming there is no change to the production configuration, tooling, or the production process itself, those contributors to learning should not see an impact.

It is also probable that minor workforce changes do not impact cost. In any large organization, there is a certain level of turnover – hires, firings, retirements – which occurs as an ordinary part of the business. “[I]t appears,” writes Cochran, “that the new manpower effect must exceed a certain ‘threshold’ level before its cost effects need be taken into account.” (Cochran, 1968.)

Nonetheless, it seems reasonable to make four assumptions about the impact of workforce changes:

- Employees new to a task will initially perform less efficiently than experienced employees.
- Over time the performance of new employees will improve relative to experienced employees.
- At some point the performance of new employees should converge with that of experienced employees.
- How long it takes to fully integrate a new employee varies depending on how much prior experience that employee has – with the industry he is working in, with the specific company he works for, with the production program that employs him, and with his or

her specific work assignment. The more familiar an employee already is with Program A, for example, the faster his performance in a new job will approach the other Program A employees already performing that job.¹

These assumptions can be illustrated graphically, as seen in Figure 3. If we use employee performance to earned standard as our baseline for efficiency, we can see that employees performing a task new to them initially perform at a higher variance factor (measured as actual hours divided by earned standards) -- which is to say, they will be less efficient relative to their more experienced peers. This delta cost premium will continue for some length of time until eventually the performance levels converge, and our new hires are no longer “new.”

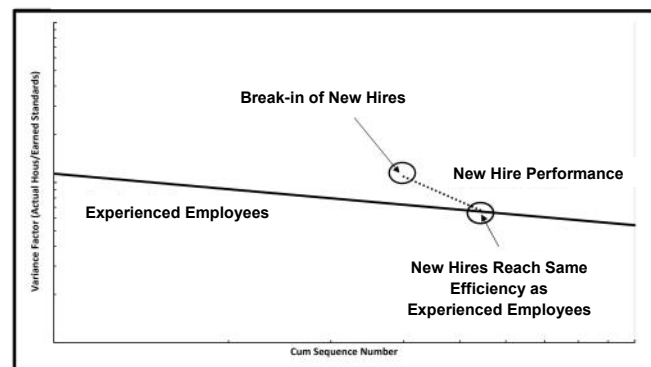


Figure 3. Theoretical Performance of New/Experienced Employees Over Time

Students of the learning curve may note that this graph looks like the cost impact of a product design or configuration change. Certainly, the two have similarities. “In both cases the work is new to the operator, the penalty is larger for events occurring further out in the production sequence, and it shrinks rapidly as production continues,” writes Cochran. “However, a workforce change is less severe than a design change because supervision, tooling, support personnel, and other crew members are left unaltered.” (Cochran, 1968.)

The graph leaves us with two unanswered questions, however. First, how much loss of

learning occurs at the point an employee begins a task new to him? Second, how long does it take for the performance of new employees and experienced employees to converge?

Naturally at this point, we turn to Cochran for guidance on the next steps. But here the usually reliable author fails us. He attempts to translate the workforce change into a “task turnover ratio,” and then use the ratio to develop the cost of the workforce change. But the “task turnover ratio” is constructed *a priori* without any reference to data and is consequently impossible to duplicate or verify. Moreover, his solution for converting the “task turnover ratio” into a cost impact is clumsy and difficult to incorporate into a model. (Cochran, 1968.) Clearly a different approach is required.

Our Study

Earlier in the paper, we identified four assumptions about the cost impact of manufacturing personnel changes. Can we verify these assumptions from actual data?

The ideal dataset would allow us to examine performance data by employee with sufficient visibility to identify if an employee was new to an area or already experienced in the work. The dataset would cover also a reasonably long period of time, allowing us to examine a “before” and “after” situation related to a major production rate change involving either a sizeable increase or decrease in workforce levels.

Employee-level data is valuable because it allows us to correlate change in cost to changes in workforce levels more easily. High-level hours per unit (HPU) data runs the risk of being contaminated by other factors that influence cost – part shortages, quality problems, etc. While we might observe increases in manufacturing hours as workforce levels changed, we cannot be certain using HPU data if the increased hours were driven by workforce, or by other factors. Employee-level

data, on the other hand, allows us to see how the performance of employees new to an area varied from that of experienced employees, giving us a greater certainty that we have really captured the cost delta associated with workforce changes only.

It was also important to identify a point in an aircraft program where the configuration as well as the planning, tooling, and build processes had stabilized. There is always a large influx of personnel at the beginning of a program as the initial aircraft are built, but it is impossible to distinguish the cost impacts related to new personnel becoming acquainted with their jobs from the seismic shifts in HPU caused by managing engineering changes, correcting planning and tooling for so-called “make-it-work” changes, the untangling of part shortages driven by late engineering, and general chaos of an aircraft development program. Likewise, a major change in the aircraft configuration creates similar confusion, albeit on a smaller scale. Only during a period of program maturity can we successfully analyze the unique impacts of a workforce change.

Fortunately, a situation arose on an Aeronautics production program which involved a substantial increase in production rates and a corresponding change in shop floor personnel headcounts. For proprietary reasons, this program will not be named in this paper, but simply referred to as Program D.

Production Intervals and Workforce Changes

Before discussing how data for Program D was collected and analyzed, a quick discussion of production intervals (PI) is in order. To measure the schedule impacts of increases or decreases in delivery rates, production management frequently refers to “production interval,” “line move rate” or “takt time.” All three terms mean the same thing: the number of workdays between product deliveries.

The PI is directly tied to delivery rates. Assume that a typical work-month has 21 planned workdays (excluding Saturdays, Sundays and holidays). To support a delivery rate of four per month, we must deliver aircraft approximately every five days. (This is calculated as 21 planned workdays per month / 4 deliveries per month = 5.25 days between line moves. If the delivery rate slows to three per month, then the line move rate increases to seven days. (This is calculated as 21 planned workdays per month / 3 deliveries per month = 7 days between line moves.) The PI and delivery rate per month are inversely related: as delivery rates increase, the PI decreases; as delivery rates decrease, the PI increases.

Program D required a significant increase in production rates to be carried out over a two-year period. For example, in the mate thru delivery area, the PI was scheduled to decrease from 4 to 2.7 to 2 over three lots, yielding a doubling of delivery rates. Other components of the aircraft, while working at different PIs due to coproduction, had similar rates of change.

Overall, the number of employees touching the aircraft during build also had to double over a two-year period. The timing of the hiring waves varied by component depending on their position

in the build sequence (component assembly was first, followed by mate and final assembly, and finally flight line). The increase in personnel was not accomplished all at once but timed with the planned decrease in PI. This meant that a given area experienced two and sometimes three distinct hiring waves.

The Method

We began by pulling weekly performance data by employee for the components under study over a 42-month period. In order not to release too much data about Program D, we will avoid identifying specific calendar years and refer to these periods as Year Zero, Year One, Year Two and Year Three. The six-month period prior to the workforce increase will be designated Year Zero. Based on staffing plans, we identified January of Year One as the beginning of the planned workforce increases. Weekly data was then accumulated through December of Year Three. The point of “full staffing” was reached earlier – in March of Year Three – but going beyond that point gave us the ability to see how long it took for performance between new and experienced employees to stabilize.

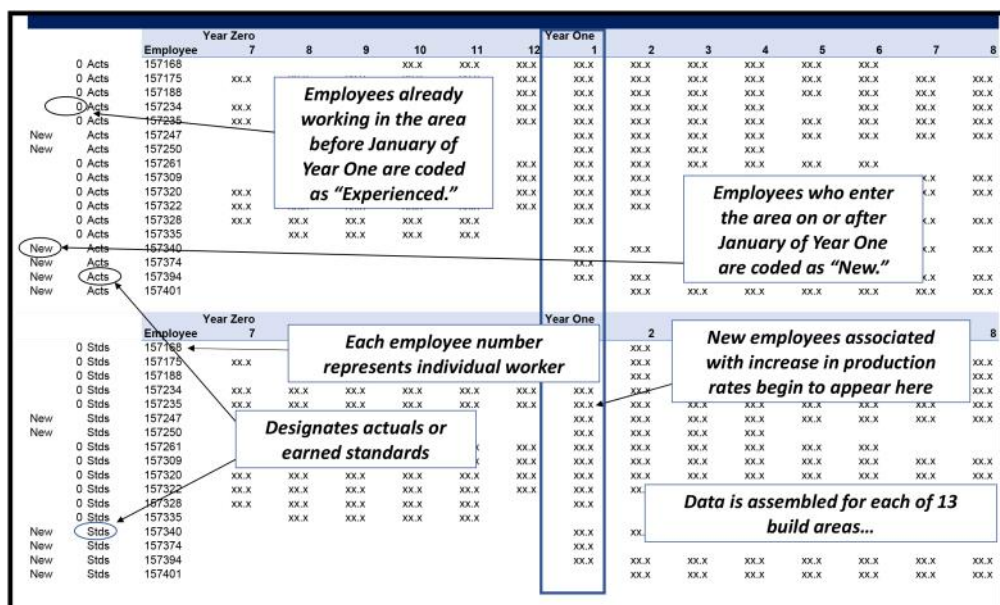


Figure 4. Example of Data Collection by Employee (Subset)

Status	Catg	Employee	1	2	3	4	5	6	7	8	9	10	11	12
New	Stds	168775	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Acts	168775	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Stds	168785	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Acts	168785	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Stds	168786	xx.x	xx.x	xx.x									
New	Acts	168786	xx.x	xx.x	xx.x									
New	Stds	168788	xx.x	xx.x	xx.x									
New	Acts	168788	xx.x	xx.x	xx.x									
New	Stds	168789	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Acts	168789	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Stds	168792	xx.x	xx.x										
New	Acts	168792	xx.x	xx.x										
New	Stds	168794	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Acts	168794	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Stds	168795	xx.x	xx.x	xx.x									
New	Acts	168795	xx.x	xx.x	xx.x									
New	Stds	168879	xx.x	xx.x	xx.x									xx.x
New	Acts	168879	xx.x	xx.x	xx.x									xx.x
New	Stds	168885	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Acts	168885	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Stds	168886	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x
New	Acts	168886	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x	xx.x

Represents the first month's performance for a given employee, once introduced into the area

Successive months represent month 2 in the area, month 3 and so forth....

Figure 5. Example of Data Stratification over Time (Subset)

The data gave us actual hours and earned standards by employee number for each component. We limited the study to assembly areas since these planned standards largely represent an engineered standard, typically constructed from predetermined time systems such as Methods-Time Measurement (MTM) data. In the old MIL-STD-1567A vocabulary, these would be Type I standards. (MIL-STD-1567A, 1983.) The fabrication areas, on the other hand, use standards developed from prior actuals (Type II standards per MIL-STD-1567A) and while, sufficiently accurate for fabrication shop management, do not demonstrate enough fidelity over time to provide us with a meaningful analysis.

Using January of Year One as a baseline, any employee who was charging to an area during the six months prior (during Year Zero) was labeled as an “experienced employee.” An examination of staffing profiles for the prior two years showed a very stable headcount by area, giving us confidence that we could safely designate these employees as “experienced” without researching everyone’s situation. Correspondingly, employees which began charging to an area after January of Year One was designated as “new.” These could be

existing employees which were transferred to a different area, or employees which were new to the company altogether. Figure 4 shows a tabular example of how the data was arranged.

The weekly data by individual build area was rolled up by month by employee and segregated by “new” and “experienced” employees. The variance factors (actual hours spent divided by earned standard hours) was used as the point of comparison.

One of the problems in the data was that each build area experienced two or three waves of new employees, making it difficult to analyze how long it took for a wave of employees new to an area to reach the same performance levels as their peers. To solve this problem, the performance data of new employees was stratified across time. We then added up the actual hours and earned standards for the first month of performance by employees and calculated a collective variance factor. We then did the same thing for month two, month three, etc. We then calculated the average variance factor for employees who were in place prior to Year One across all months to calculate a baseline for comparison. Figure 5 shows an example of the data stratification.

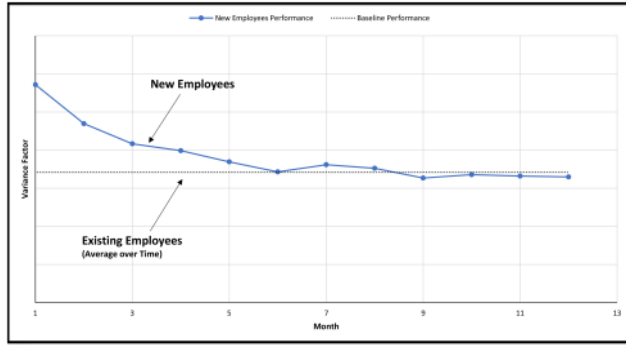


Figure 6. Comparison of New/Experienced Employee Performance by Month Since Introduction - Example Build Area

This allowed us to construct charts by build area like Figure 6.

In their first month after introduction to a new area, the performance of employees was worse than the baseline performance of their experienced peers. This improved over the succeeding months until – in this case – the performance of the two groups converged at month six.

Across all build areas, the performance of employees new to an area was initially worse than that of experienced employees. Most areas (10 of the 13 build areas) showed convergence or near-convergence (defined as achieving a less than 10 percent difference) to the baseline over varying lengths of time. The median length of time for convergence was nine months.

This gives us the opportunity to validate our four assumptions:

- New employees had worse performance initially than their experienced peers.
- New employees improved their performance relative to more experienced employees.
- In most cases, there was convergence of new employee performance back to the baseline.
- The median timeframe of that convergence took nine months.

Using this finding, the data labels were reconfigured. For the first nine months after introduction to an area, individual employees were classified as “new.” For month 10 and on, those same employees were now considered “experienced.”

This allows us to show performance by new and experienced employees over time and see the overall performance delta over time. Figure 7 shows the variance factors for a sample build area plotted on the first Y axis, with the number of employees counted as “new” (subject to the nine-month time frame) plotted against the second Y axis.

By calculating this performance delta in terms of performance to standard, we can also calculate the estimated hours impact of introducing new employees. The cost of integrating new employees for a given month is calculated using the following formula:

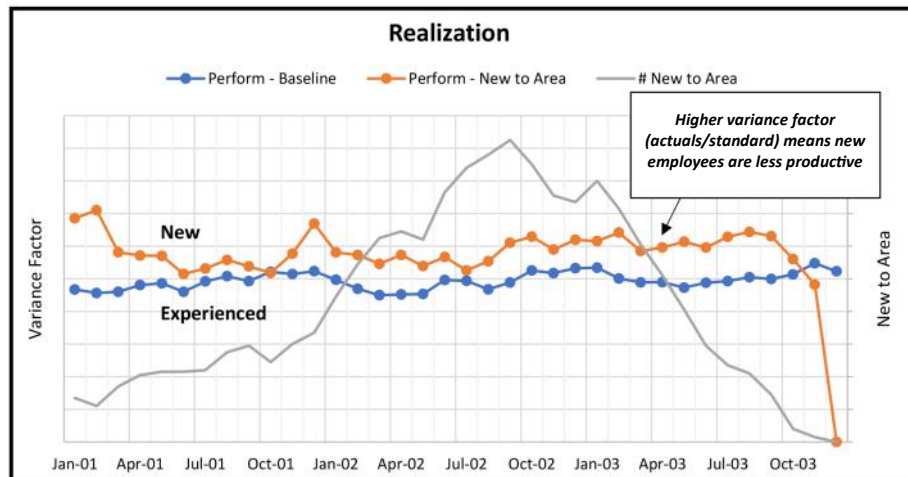


Figure 7. Comparison of New/Experienced Employees (Subject to Nine-Month Limit) Over Time – Sample Build Area

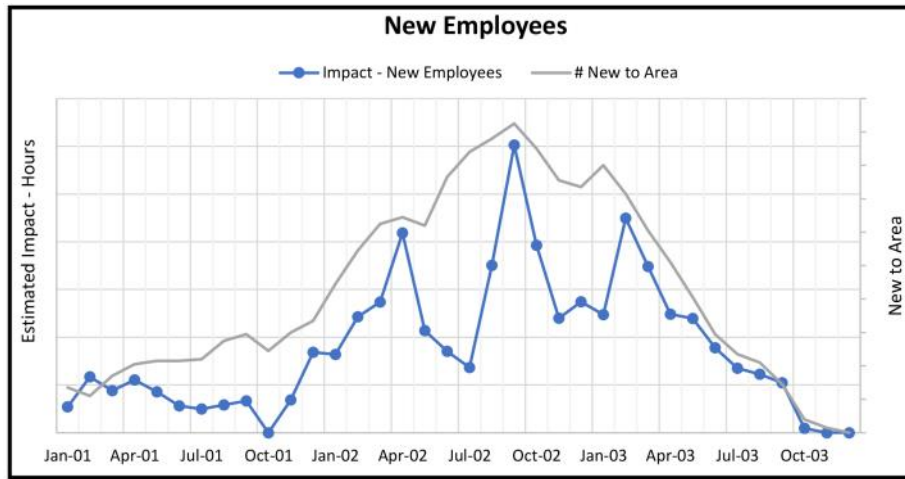


Figure 8. Cost Delta for New Employees Correlated to Number of Employees New to Area – Sample Build Area

$$H_d = H_s \times (V_n - V_e)$$

where H_d = delta cost (hours) of integrating new employees for a given month, H_s = total earned standards by new employees for a given month, V_n = monthly variance factor for new employees and V_e = monthly variance factor for experienced employees.

We can now look for the correlation between the hours delta attributable to introducing new employees against the number of employees considered new to the area at any given point in time. An example of this is given in Figure 8.

Our goal now is to calculate some useful relationship between the level of workforce changes and the resulting cost impact. To do this, all the data was aggregated across the build areas

by month. For each month, the following data was calculated:

- Percent of new employees (number of new employees divided by the number of total build employees)
- Percent cost delta (delta hours associated with new employees divided by the total number of hours charged)

This allowed us to relate the two variables and see the relationship plotted on a log-log space in Figure 9.

For proprietary reasons, the value of the intercept is omitted. However, since the value of the logarithmic coefficient is close to unity, the relationship approaches a linear relationship. The R-square fit is excellent, and the model explains virtually all the observed variation.

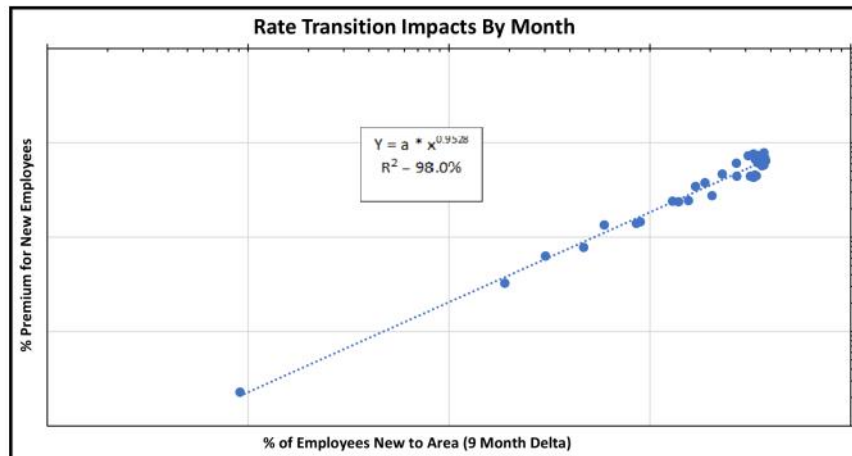


Figure 9. Observed Relationship Between New Employees and Associated Cost Premium

Length of the Recovery Period

This study represents, in many cases, a worst-case scenario. First, Program D’s workforce doubled over an approximately two-year period. Most workforce increases or decreases are not so severe. Second, this workforce increase was accomplished in successive, overlapping hiring waves. Most workforce increases or decreases occur at as one-time discrete events. Finally, many of the new employees were not simply new to the program or the company, but new to the aerospace industry in general.

This suggests that the nine-month recovery period could be shorter under other rate change scenarios. For example, a smaller workforce increase could transfer workers already in place on the shop floor but currently working on a different program. It is logical to suppose that those transferred employees will not take as long to acclimate themselves to their new jobs. In the case of a work reduction, the remaining employees are already on the program, but they may have to learn some new tasks. Theoretically this recovery period would be even shorter.

Application of the Model and Approach

Now that we have built this model, how is it applied?

The ideal situation would allow us to work from a detailed staffing forecast. That forecast would tell us how many heads need to be added or deleted and the timing of those impacts. However, this data is not always available – for example, our company may not have detailed forecasts longer than a year out.

However, using production interval and estimated hours per unit, we can approximate headcount levels in order to use the model. Note that the

model depends on relative changes in headcount, and not absolute values. If we can correctly approximate the magnitude of the change, the answers that are returned should be good.

Table 1 provides an example of how we can calculate a relative headcount change using this information. We assume at unit 600 a production interval change takes place which will create a workforce reduction. Based on this information, we can calculate a relative headcount change and the associated ratio of new/reassigned task shown in Table 1.

Two caveats should be noted. First, this calculation will provide a value of full-time equivalent heads. In fact, due to absences (vacation, sick leave), overtime, or time charged to indirect efforts, the actual yield rate per employee could be more or less than a simple workdays per month multiplied by hours per day. However, since our interest is in the relative change in headcount, these refinements should not significantly alter the values or cause difficulties. Second, this approach also ignores the possibility at very low production rates, a minimum staffing level must be maintained in order to preserve critical skills. Where such a

Unit Break-in of Change			600			
Estimated Hours per Unit (HPU) at Break-in			5,000			
Average Work Days per Month			21			
Number of Hours per Day			8			
	Production Interval (PI) (Days)	Delivery Rate per Month				
Before Change	10.5	2.00				
After Change	14	1.50				
	HPU	Delivery Rate per Month	Hours per Month	Work Days per Month	Hrs per Day	Operators
Before Change	5,000	x 2.00	= 10,000	/ [21 x 8]	=	60
After Change	5,000	x 1.50	= 7,500	/ [21 x 8]	=	45
			Headcount Reduction			15
* Delivery rate calculated as: Average Work Days per Month / Production Interval						
Task Reassigned to Remaining Operators:						
	Operators Reduced			15		
	Total Operators before Reduction			60		
	Percent Reassigned Task			25.0%		
* 25.0% reduction in operators, so 25.0% of task will be new to remaining operators.						

Table 1. Assembly Workforce Reduction

potential exists, the estimator should consult with his Industrial Engineering department to establish such a minimum skill level and adjust his calculations appropriately.

Having calculated a 25% reassignment ratio, how do we translate into a cost impact? First, we must assume how long the disruption will last. We might imagine three general separate scenarios which could occur:

Scenario A, Workforce Reduction: The reduction is accomplished within the program, with work reassigned to existing employees. While these workers must learn some new tasks, they are already familiar with techniques peculiar to the program. This scenario will have the shortest recovery period.

Scenario B, Workforce Increase: The increase is accomplished by transferring workers from other company programs. While familiar with the aircraft industry as well as the company “way of doing business,” these workers will not be familiar with techniques peculiar to the program. In addition, some existing workers will be reassigned to different roles in order to help balance crews and optimize workflow. This scenario will have a recovery period somewhere between Scenario A and C.

Scenario C, Workforce Increase with Outside

Hires: The increase is largely accomplished by hiring workers from outside the company. These workers are not only unfamiliar with the unique program peculiarities, they are also unfamiliar with the company’s way of doing business. They may not even have prior experience in the aircraft industry.

This scenario will have the longest recovery period.

Our previous empirical study falls squarely into Scenario C. Therefore, the median nine-month recovery period would represent the “worst case.” While it follows logically that Scenario A will have the shortest recovery period, with Scenario B falling somewhere between A and C, it is difficult to establish *a priori* exactly how long these periods will last. The estimator should consult with Production management team and the Industrial Engineering department to help him make the best determination.

For the purposes of our example, we have assumed a four-month period of recovery on the grounds that our situation corresponds most closely with Scenario A. Table 2 shows the calculations. It is first necessary to calculate the undisrupted HPU and spread those hours across time. Although our PI change is scheduled to take place in January effective unit 600, it is important to note that any component in work in January, even ones started prior to unit 600, can be impacted by the personnel change. That is because the “bumping” of personnel to accommodate the workforce reduction is likely to reassign workers across stations, potentially affecting any unit currently in work.

For proprietary reasons, the actual cost equation

Unit	Hours per Unit	Start Date	Percent Reassigned Task				25.0%	25.0%	25.0%	25.0%	Disruption Hours
			Percent Cost of Reassignment				x%	x%	x%	x%	
			Spread of Hours By Month				Percent Cost of Reassignment				
			Jan	Feb	Mar	Apr	Jan	Feb	Mar	Apr	
595	5,010	15-Oct	5.6%				x%				ZZZ
596	5,008	1-Nov	22.2%				x%				ZZZ
597	5,006	15-Nov	44.4%	5.6%			x%	x%			ZZZ
598	5,004	1-Dec	55.6%	22.2%			x%	x%			ZZZ
599	5,002	15-Dec	44.4%	44.4%	5.6%		x%	x%	x%		ZZZ
600	5,000	1-Jan	22.2%	55.6%	22.2%		x%	x%	x%		ZZZ
601	4,998	22-Jan	5.6%	44.4%	44.4%	5.6%	x%	x%	x%	x%	ZZZ
602	4,996	12-Feb		12.5%	52.8%	33.3%		x%	x%	x%	ZZZ
603	4,994	4-Mar			22.2%	55.6%			x%	x%	ZZZ
604	4,992	25-Mar			1.4%	33.3%			x%	x%	ZZZ
605	4,990	15-Apr				5.6%				x%	ZZZ
											Z,ZZZ

For ship #600, disruption hours = 5,000 hrs x [(22.2% * x%) + (55.6% * x%) + (22.2% * x%)] = zzz hours

* Date of PI Change: 1 January
 * Assumed Months of Recovery: 4 months (January through April)
 * Total Build Span: 3 months
 * Percent Cost of Reassignment: Not shown due to proprietary reasons. This is percent cost delta correlated with Percent Reassigned Task.

Table2. Calculating Cost of Reassignment

cannot be released. We will assume that a 25% reassignment ratio relates to a cost premium of $x\%$. Therefore, for the month of January, the total HPU for a given unit number is multiplied by the percent of task completed that month times $x\%$. The result provides us the disruption expected for January. Similar calculations are performed for the month of February, March and April. Since we have assumed the impact ceases after four months, our calculations cease after April.

In the end, our disruption will impact 11 units (unit numbers 595 through 605). It can be inferred that the number of aircraft impacted will increase at higher production rates (or longer production span times) since there will be more work in process at any given time, and therefore more opportunity for additional aircraft to be disrupted by workforce changes. For our example, the total disruption will look something like Figure 10.

This distribution is different from the

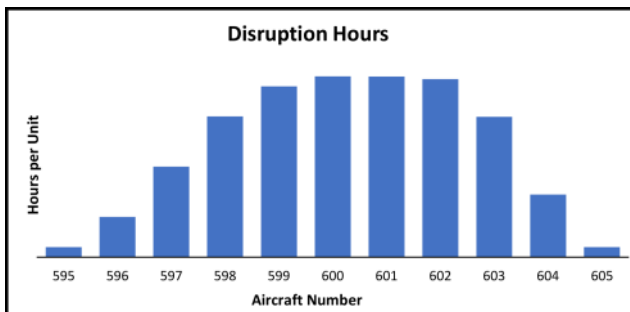


Figure 10. Disruption Hours by Unit

theoretical construct supposed in Figure 3. In that case, the units prior to the break-in aircraft for the rate change would be unaffected. But this theoretical construct does not really account for the “bumping” effect, which is likely to spread the disruption across any unit in work at the time of the workforce reduction.

It could be argued that if new or reassigned workers become more proficient over time that the value of x will also change over time – that it should be higher in the first month of disruption

and decrease over the four-month period until reaching the termination point, following the pattern we observed in Figure 6. This adjustment will potentially alter the shape of the distribution of disruption hours by unit. Such a feature could be incorporated into the model, but for simplicity of explanation a flat percentage has been assumed for each of the four months of impact. Depending on the estimator’s specific needs, precision at the individual unit may be traded off for simplicity of presentation and calculation.

Next Steps


As always, further research remains. Testing of the model in future instances of production rate increases or decreases will provide insight to its accuracy and the need for further refinements. In addition, data collection surrounding smaller-scale workforce increases or decreases will provide further insight into the length of the recovery period. Our empirical research has established the outer bound of the time between initial disruption and eventual recovery to the underlying performance trend for a large workforce expansion. But we have supposed that this is the worst case, and for workforce reductions, cases of pure turnover, or smaller workforce increases, we are left to judgmentally decide how long the recovery period should be. Further research will reduce that element of judgment and provide the estimator more precise guidance, as well as verification that the model provides accurate predictions in those specific scenarios.

Conclusion

In the idealistic world of learning curve literature, fluctuations in delivery rates or the potential disruption created by “green labor” are frequently ignored or else assumed away. Its silence suggests that these matters are not worthy of much consideration.

Charles E. Ferguson, an economics professor at Texas A&M University, facetiously defended himself to students who demanded to know how theoretical economics related to the problems of the real world by saying: "The real world is a special case -- and not a very interesting one at that." The academic can strike such a pose. But cost estimators must live in – and produce estimates for – the real world.

Changes in production rates and the associated impacts on workforce numbers and experience levels remain one of the production estimator's

greatest challenges. This paper aims to bring these issues to light and provide an analytical framework for these changes. It also provides a model for forecasting the impact of these changes based on analysis of a real-life case study of a workforce expansion. This analysis is presented not as the final word on the subject. As John Maynard Keynes reminds us, "It is better to be roughly right than precisely wrong." It is hoped that this paper will stimulate further discussion in the estimating community on practical solutions to handle one of the common production issues. 

Footnotes

¹ Compare these to the assumptions of RAND's 2004 model to assess changes in shipbuilding labor: "(1) It takes three years to become fully proficient at a trade; (2) worker productivity improves linearly with experience to a fully qualified status, beyond which no further productivity is modeled; (3) a worker with no experience has a productivity of two-thirds that of a fully proficient worker; and (4) the changes of hiring a worker at any experience level are identical." (Arena, 2004.)

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Brent Johnstone is a Lockheed Martin Fellow and production air vehicle cost estimator at Lockheed Martin Aeronautics Company in Fort Worth, Texas. He has 33 years' experience in the military aircraft industry, including 30 years as a cost estimator. He has worked on the F-16 program and has been most recently the lead Production Operations cost estimator for the F-35 program. He has a Master of Science from Texas A&M University and a Bachelor of Arts from the University of Texas at Austin.



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4115 Annandale Road, Suite 306 | Annandale, VA 22003

703-642-3090 | iceaa@iceaaonline.org