Learning Curve Setbacks: You Don't Always Move DOWN a Learning Curve

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There are a number of reasons why production, continually moving down a known learning curve will suddenly retrace its steps by moving up the learning curve. The cause of such a reversal needs to be recognized and the impact determined. Knowing how to compute the degree of "forgetting" is crucial in properly estimating future production times and costs. This paper will address how to effectively determine the impact of such events on the learning curve and how to make changes to future estimates.

INTRODUCTION

Production efficiencies are expected to take place thanks to the learning effect which says that as a worker or an organization gains experience, the resources needed to perform a task are reduced as the experience continues. The reduction in time or cost due to the learning effect has been well documented in the literature (see for example: Yelle, 1979). The degree of improvement has been documented to take place at a consistent rate with each doubling of experience (Wright, 1936). Being aware that such consistent improvement will continue allows estimators to better estimate the production time or cost far into the future once the appropriate learning rate is determined. (Note: for brevity, throughout the remainder of the paper, the term "cost" will be used to refer to productions costs in dollars or hours.) Such recognition comes with a caveat. The estimates will only be reliable if the production process being monitored remains unaffected by outside events. Unfortunately, events capable of derailing a process and its learning curve are not that infrequent.

The most common disruptive events to the learning curve which affect future production costs are (1) interruption to the manufacturing process, (2) changes to the design of the product being produced, and (3) changes to the manufacturing process. The first of these will usually result in an increase in future costs. The second and third could result in an increase or a decrease in future costs and perhaps changes to the slope of the learning curve. This paper will address these three events through examples, their immediate impact on the learning curve as well as their impact on future costs. Understanding the proper way of dealing with these events will ensure that future cost estimates will remain reliable.

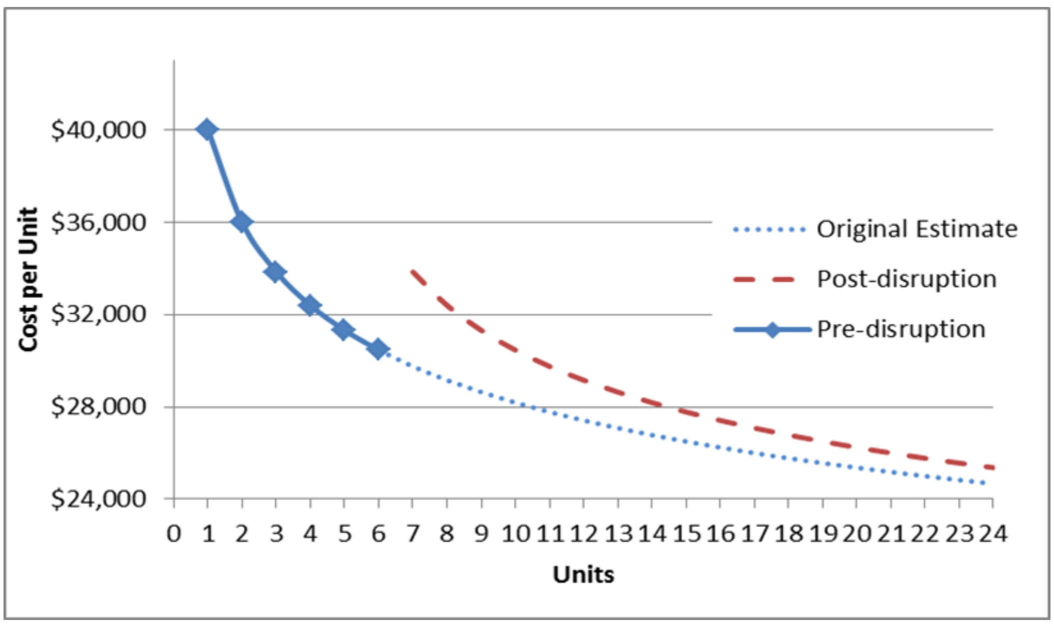
DISRUPTIONS TO THE LEARNING PROCESS

Disruptive events to the learning curve are fairly common in industry today. Some disruptions, such as those caused by a production stoppage, can result in long-term cost increases compared to the original costs. For example, it is very possible that during a disruption, one or more of the production workers has been permanently reassigned to a different production area or is laid-off only to be unavailable later. In either case, the worker would not be returning to their old job after the disruption, but instead would be replaced by a worker with little to no prior experience at this job. In addition, as the duration of the disruption increases, workers' memory about the activities of their job will slowly fade resulting in slower performance times (higher costs) when production resumes. Unfortunately, many such events occur with little warning providing scant opportunity for a production manager to avoid the effects.

Other disruptions, such as those caused by redesign of the product or by the installation of improved manufacturing processes can also impact future costs. These events would be known in advance, but their impact on the learning curve and production times could still prove uncertain.

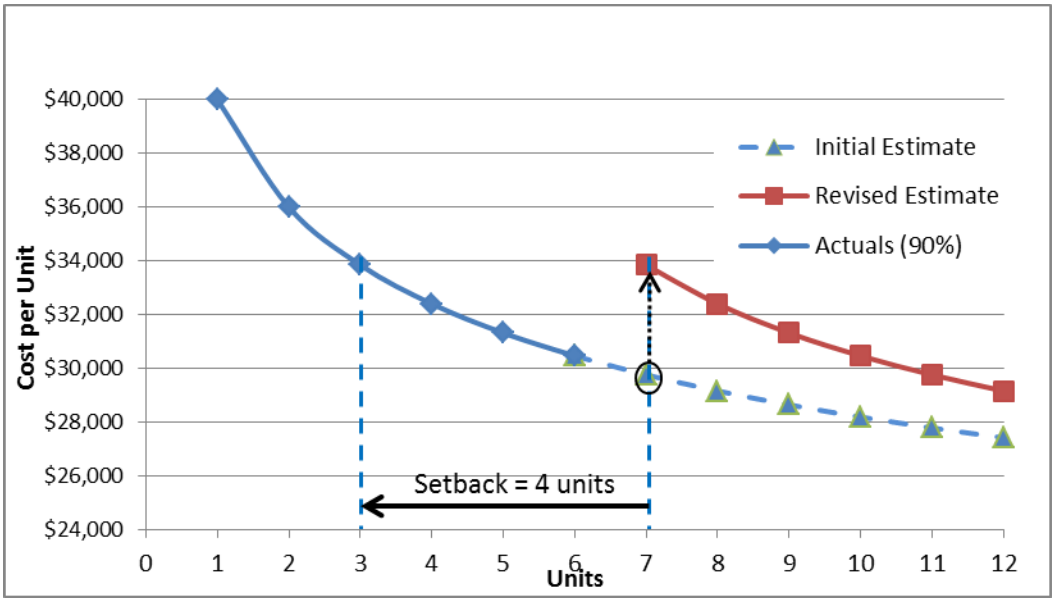
Regardless of the cause of the disruption, it would be beneficial if an estimator could evaluate an upcoming disruption and postulate the degree to which it would affect future costs *ex ante*. However, in most cases, such foresight is usually impossible since the impact of disruptions depends on many factors – most of which cannot be evaluated until after the event takes place. Due to the uncertainty of the impact of a disruption, it is better for the estimator to measure the impact once production is restarted. The impact will be most recognizable when plotting production times on a learning curve (see Figure 1). Such a plot will provide the evidence needed to determine not only the direction of the change in costs but also the magnitude.

FIGURE 1
EFFECT OF DISRUPTIONS TO LEARNING PROCESS



If the costs of post-disruption production units are compared to the cost of pre-disruption units, the higher cost of a post-disruption unit will be observed to be equal to that of a unit previously produced (i.e., prior to the disruption). The degree of *setback* on the learning curve for this item will be revealed by comparing the unit number of the first post-disruption unit with that of a previously produced unit whose cost equaled this post-disruption unit's cost, as in Figure 2. The term "setback" refers to the extent to which learning was lost, or set back, during the disruption. Setback is described in "units" indicating how many units of progress on the learning curve were lost, or unlearned. While the impact of the disruption will decrease over time, the effect will be felt by all post-disruption production for the life of the product.

FIGURE 2
SETBACKS CAUSED BY DISRUPTIONS TO LEARNING



ESTIMATING THE IMPACT OF INTERRUPTIONS TO THE MANUFACTURING PROCESS

One of the most frequent disruptions to the learning process is an interruption to the manufacturing process. The potential causes of production interruptions are numerous and naturally vary by industry. A firm might have a mandatory shutdown from Christmas through New Year's; another firm might experience a labor dispute resulting in workers walking off the job for some period of time; at another company an unanticipated event might cause the supply chain to be negatively affected (e.g., train derailment) causing delays in receipt of necessary materials resulting in a shutdown; a severe natural event (e.g., Hurricane Katrina) might cause a temporary closure of an assembly facility or the facilities of suppliers, etc. A more detailed example should clarify the corrective actions needed by the estimator.

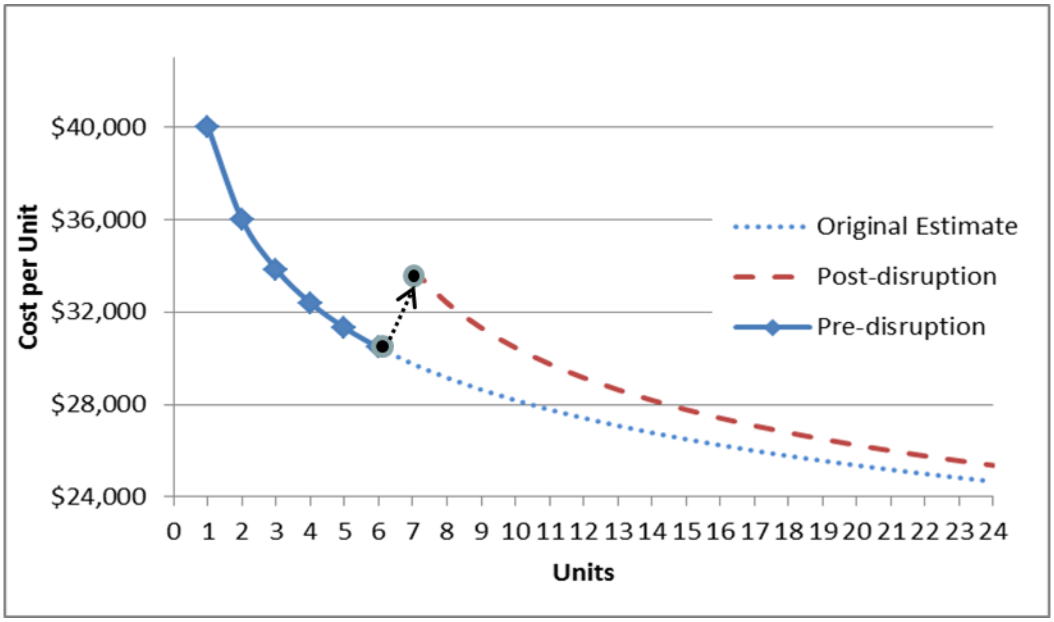
Example

A large aerospace company successfully bid to provide the U.S. Air Force with periodic diagnostic testing of their F-16 Fighting Falcon. In the agreement, the U.S. Air Force was to deliver one F-16 to the firm's test facility every month for the next 24 months (the term of this contract). During the time available, the firm would perform testing of the aircraft's electronic systems. In bidding for this contract, the firm provided the Air Force with a cost estimate based on per aircraft cost that was expected to decrease with every plane serviced following along a 90 percent learning curve. The learning effect was incorporated into the bid because of the repetitive nature of the testing process. The firm estimated the cost of servicing the first aircraft to be $40,000. The firm was awarded the contract. Two months after being awarded the contract, and right on schedule, the first F-16 arrived at the testing facility. Each month thereafter an F-16 arrived for testing on the first of the month. On the seventh month into the contract no aircraft was delivered. The eighth month came and still no aircraft. Despite numerous inquiries to the Air Force, no aircraft where delivered during the 15 month period since the last aircraft was tested. Finally, nearly two years after the first aircraft came in for service the seventh aircraft arrived: no notice, no excuses, it just arrived for servicing.

The sudden arrival of a new aircraft caught the aerospace company off guard due to lack of communication from the Air Force. The company was unable to begin testing the jet's electronics because several things had happened within the firm since the last aircraft was tested over 15 months ago: some of the personnel had been reassigned to other projects and were dispersed throughout the country; some had retired; and some of the test equipment had been appropriated by other departments within the company for their own projects.

The effect of the disruption was very obvious when the cost of testing the latest aircraft was graphed on the previously developed learning curve. Figure 3 shows the actual costs of the first six aircraft tested (solid line), the actual cost of the first post-disruption aircraft (circle), the estimated costs for all post-production aircraft (dashed line) and the original estimated cost of aircraft (dotted line) on a 90 percent learning curve.

FIGURE 3
COST INCREASES CAUSED BY INTERRUPTIONS TO THE MANUFACTURING PROCESS



It is quite clear that the cost of the post-disruption aircraft is notably higher than originally estimated. The increase in costs can be traced directly to the disruption. If the original contract was for 24 aircraft, we need to be able to estimate the cost impact of the disruption on the remaining tests under the contract. Management of the company believes the Air Force's actions caused the costs to go up and therefore is responsible for the cost overages associated with the disruption.

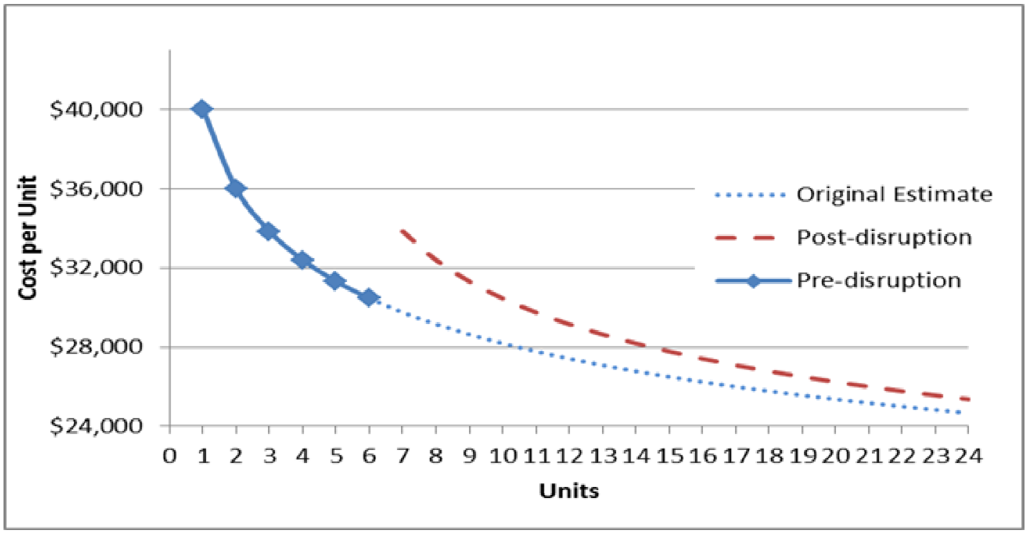
The size of the setback (4 units) in the aerospace example will remain constant throughout the remainder of the project (Norfleet, 2004, p. 10.5). It would be expected that the cost of Unit 8 would be equivalent to pre-disruption Unit 4 (8-4); the cost of Unit 9 would equal that of Unit 5 (9-4), etc. To properly adjust the estimates for the remainder of the contract, the unit numbers for *all* future units must be decreased by 4 and then each unit's cost should be recomputed. Applying the setback in this way will allow for the proper correction of cost estimates in order to properly reflect the impact that the disruption had on all subsequent aircraft for the remainder of the contract. Table 1 shows the calculation of the expected cost overruns from the time of the disruption to the end of the contract. It is clear that this contractor incurred over $28,000 in added expenses due to the disruption caused by the Air Force.

TABLE 1
COST IMPACT OF PRODUCTION INTERRUPTIONS

Unit	Original Estimated Costs	Equivalent Unit Number after Setback	Post-Disruption Estimated Costs	Expected Cost Overruns due to the Disruption
	$40000(x)^{-.152}$		**$40000(x-4)^{-.152}$**	∆
1	40,000			
2	36,000			
3	33,848			
4	32,400			
5	31,320			
6	30,463			
	DISRUPTION			
7	29,758	=7-4=3	33,848	4,090
8	29,160	=8-4=4	32,400	3,240
9	28,643	=9-4=5	31,320	2,677
10	28,188	=10-4=6	30,463	2,275
11	27,782	=11-4=7	29,758	1,976
12	27,417	=12-4=8	29,160	1,743
13	27,086	=13-4=9	28,643	1,557
14	26,782	=14-4=10	28,188	1,405
15	26,503	=15-4=11	27,782	1,279
16	26,244	=16-4=12	27,417	1,173
17	26,003	=17-4=13	27,086	1,082
18	25,779	=18-4=14	26,782	1,004
19	25,568	=19-4=15	26,503	935
20	25,369	=20-4=16	26,244	875
21	25,182	=21-4=17	26,003	822
22	25,004	=22-4=18	25,779	774
23	24,836	=23-4=19	25,568	732
24	24,676	=24-4=18	25,369	693
Total Project	**$684,011**		**$712,346**	**$28,335**

When graphed (see Figure 4), the apparent impact of the setback appears to be decreasing and the rate of learning seems to be steeper than the original curve. This is only an apparition due to two factors. First, the setback is a fixed number of units (4 in this case) being applied horizontally to a logarithmic function. Second, the plotting of the revised estimates being set back four units causes the bigger reductions taking place at earlier units to be plotted later on the learning curve (further to the right). The slope of the underlying learning curve has not changed from its original 90%, but due to the above reasons, the post-disruption learning curve becomes distorted. Rather than being a steeper learning curve, the line in Figure 4 is depicting a learning curve whose slope is changing as the time since the disruption event increases.

FIGURE 4
LESSENING OF DISRUPTION IMPACT



In learning curve theory, the rate of improvement can be determined by dividing the production time of a particular unit by the production time of a unit produced with half the prior experience (Teplitz, pp. 58-59). To measure the changing of the slope of the curve seen in Figure 4, we can compare the revised estimate at unit 14 to that of unit 7 (where unit 14 is a doubling in experience compared to unit 7). In Table 2 we see that the ratio of the later unit's revised estimate to that of the earlier unit ($28,188/$33,848) depicts a rate of improvement between these two points of 83.3%. This is much higher than the true 90% improvement rate in this problem. Comparing the revised estimate at unit 24 to that of unit 12 (also a doubling in experience), we see that the ratio of the later unit's revised estimate to that of the earlier unit ($25,369/$29,160) depicts a rate of improvement between these two points of 87%, much closer to the underlying 90% curve. As the disruption event becomes further in the past, its impact on the learning rate decreases and the revised learning curve approaches the true underlying rate of 90 percent.

TABLE 2
POST-DISRUPTION LEARNING CURVE APPROACHES UNDERLYING LEARNING RATE

Unit Comparisons	Cost of Later Unit	Cost of Earlier Unit	Ratio	Learning Rate
7 and 14	$28,188	$33,848	0.8328	83.3%
8 and 16	$27,417	$32,400	0.8462	84.6%
9 and 18	$26,782	$31,320	0.8551	85.5%
10 and 20	$26,244	$30,464	0.8614	86.1%
11 and 22	$25,779	$29,758	0.8663	86.6%
12 and 24	$25,369	$29,160	0.8700	87.0%

ESTIMATING THE IMPACT OF CHANGES TO THE DESIGN OF THE PRODUCT OR THE MANUFACTURING PROCESS

Changes to the design of the product or to the manufacturing process itself impact the learning process in the same way and can impact future production costs just as interruptions to the manufacturing process did. The impact on these costs can be positive or negative depending upon how the change would affect the manufacturing of the redesigned product.

Negative Impact to the Learning Process

Some product redesigns entail adding enhancements to the original product to make the product more appealing to the potential purchaser. These enhancements often require the production team to perform more or lengthier tasks than were performed on the original product. These changes will require new learning to take place on some elements of the production process and will be demonstrated by part of the production process setting back to unit number one while the unchanged portion of the production process will continue down the original learning curve.

Example

A little over a year ago, a general contractor was chosen to build a new 100-unit housing development. While the new development would consist of 3 uniquely designed two-story homes, the second floor interior was the same for all models. This consistency meant that those construction workers (e.g.: framers and drywallers) building the interior on the second floor would gain expertise as they progressed from house to house across the housing development. Their improvement was consistently tracked along an 85 percent learning curve.

After constructing 40 of the 100 units, the developer and architect decided to modify the second floor by taking the space from a loft area at the top of the stairs and incorporating it into the master bedroom. The architect explained to the construction foreman that the design change simply meant that an existing wall would be continued further than it had been originally and the doorway within that wall would be relocated to the other end of the wall from where it was before. He assured the foreman that these simple changes would not impact the construction time because it was just more of the same wall and the effort of putting in the door was no different than it was before, except in a different location. With blueprints in hand, the foreman explained the changes to the framers and the drywall installers.

Over the course of constructing the next ten houses, the foreman noticed that the framers and drywall installers seemed to be taking more time on the second floor than in the past. The problem was that part of the second floor work was set back on the learning curve since the framers and drywall installers had no previous experience with this new design of the second floor. Their work in the rest of the second floor was not affected and the task times continued down the original learning curve. What has happened is that the while some of the tasks have continued down the original learning curve, workers have encountered tasks which need to be learned for the first time, such as where partial sheets of drywall will need to be cut compared to where this happened before.

Calculating the production cost after the disruption can be determined by tracking the old learning curve for the unaffected area and the new learning curve for the affected area. Suppose that it was determined that 75 percent of the original framing and dry wall production time would be unaffected by the redesign and would continue down the original learning curve, but that 25 percent of the original framing and drywall activity time would be replaced with a new set of tasks in which the worker time would be set back to the beginning of the curve.

The splitting of the second floor learning curve can be seen in Figure 5. In Figure 5, “B” represents the learning curve for the unaffected work on the second floor. “A” represents the learning curve for the new tasks. The new combined time for house 41 and beyond is represented by curve “C”.

FIGURE 5
SPLITTING THE LEARNING CURVE DUE TO PARTIAL REDESIGN

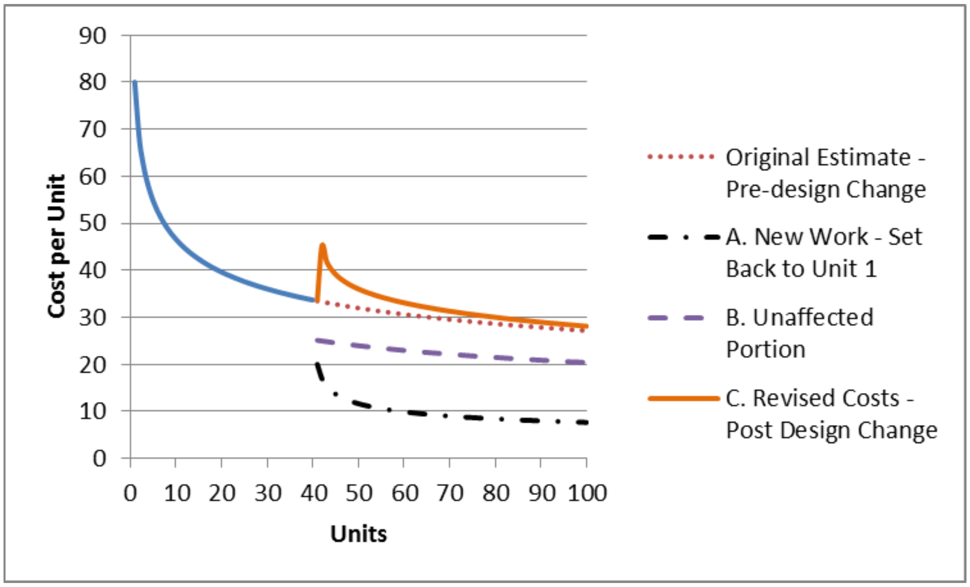


Table 3 shows the calculations for the second floor framing and dry wall for the remainder of the project. It will be assumed that the rate of improvement for the new tasks will be equal to that of the original tasks. The design change cost the developer 141.7 extra hours of labor for the remaining houses due to the addition of tasks not previously performed.

Positive Impact to the Learning Process

Many products are redesigned specifically to make the manufacturing process simpler in order to reduce costs. Such redesigns often eliminate some of the manufacturing operations or reduce the number of complex tasks. The learning curve for this item could show a marked reduction in the per unit cost beginning with the first unit of the redesigned product (see Figure 6a). It is also possible that a redesign would result in a manufacturing process with fewer opportunities for learning which would cause the slope of the learning curve to become flatter beyond the point at which the newly designed product would resume production (see Figure 6b). These figures are graphed using a log-log scale which results in the logarithmic learning curves being demonstrated as straight lines. As such, it becomes easier to see the effects of these positive design changes on production costs.

TABLE 3
COST IMPACT OF DESIGN CHANGE

Unit	Original Estimated Costs	A. Estimated Cost of Unaffected Work	Equivalent Unit Number after Setback	B. Estimated Cost of Newly Added Work	C. Estimated Total Cost	Expected Cost Overruns due to the Disruption
	$80(x)^{-.23447}$			**$20(x-40)^{-.23447}$**		Δ
1	80.0	80.0				
2	68.0	68.0				
.						
.						
.						
40	33.7					
		DESIGN CHANGE				
41	33.5	25.1	1	20.0	45.1	
42	33.3	25.0	2	17.0	42.0	
43	33.1	24.8	3	15.5	40.3	
44	32.9	24.7	4	14.4	39.2	
.						
.						
.						
98	27.3	20.5	58	7.7	28.2	
99	27.2	20.4	59	7.7	28.1	
100	27.2	20.4	60	7.7	28.0	
Total Project	**3500.3 hrs.**	3053.7 hrs.		588.3 hrs.		141.7 hrs.

FIGURE 6A
PRODUCT SIMPLIFICATION

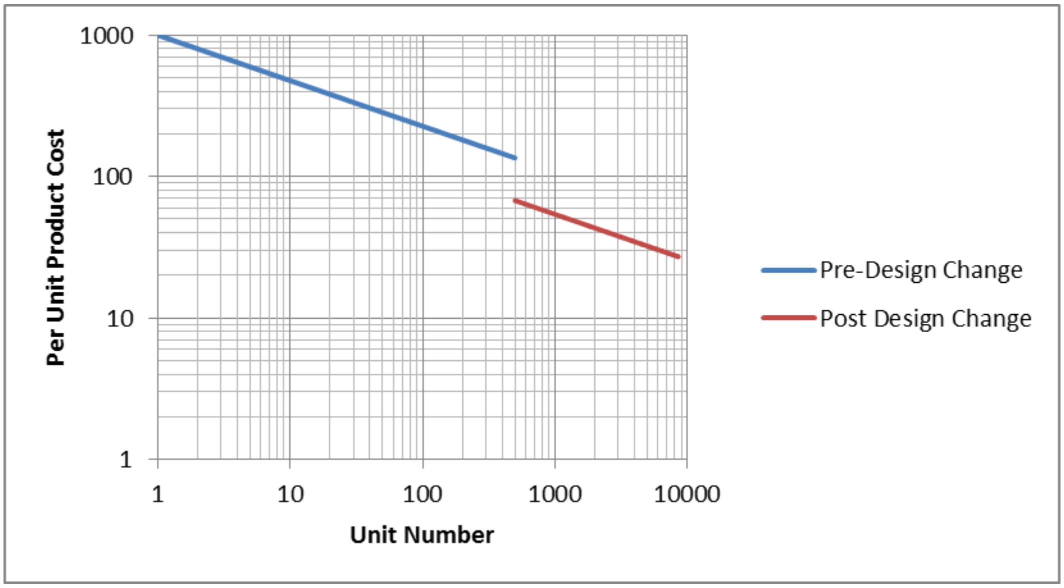
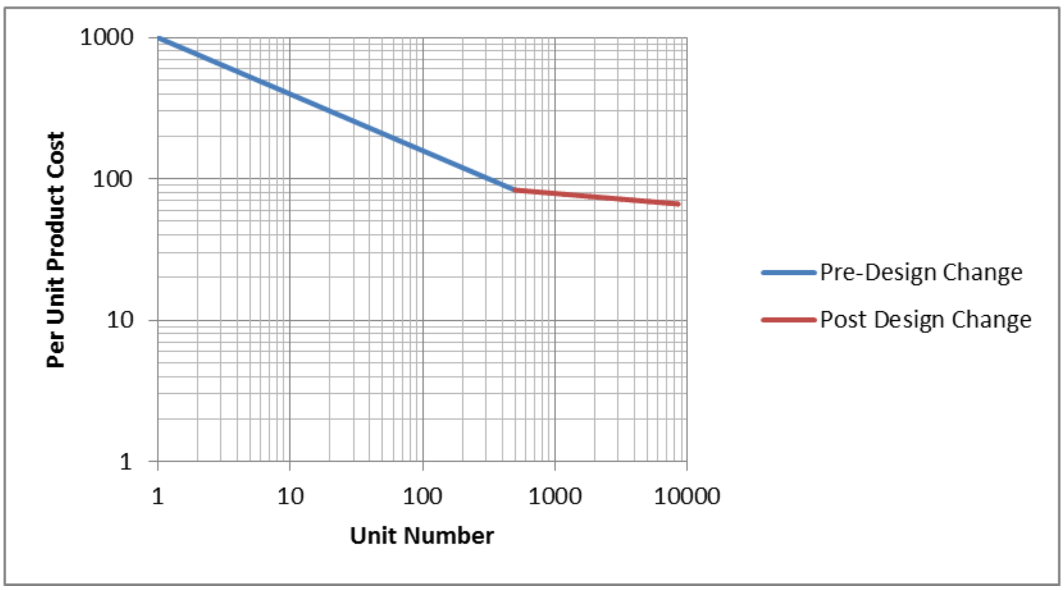


FIGURE 6B
PRODUCT SIMPLIFICATION – CHANGE IN LEARNING RATE

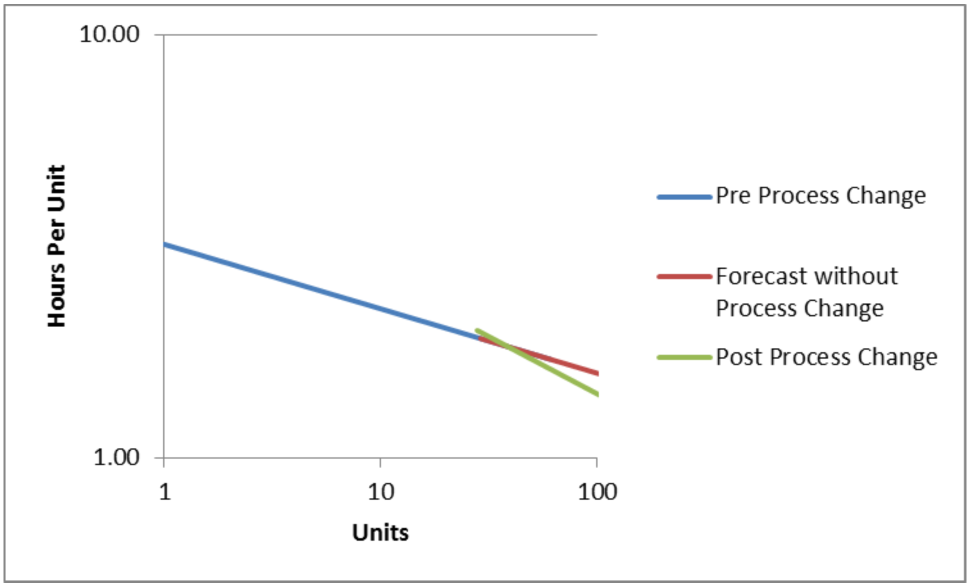


Example

The manufacturer of flat-screen televisions had been producing 42 inch televisions for a number of years maintaining a dependable manufacturing process that consisted of several workers interfacing with NC (numerically controlled) machines. Engineers in the firm have been working on a more efficient process that used smarter CNC (computer numerically controlled) machines but that would still require the same number of workers as the current process. Implementation of the new process was expected to result in a considerable reduction in per-unit production costs.

Upon installation of the new CNC machines and implementation of the other process changes, rather than demonstrating the anticipated manufacturing cost reductions, the costs associated with the 42 inch television increased slightly. Investigation revealed that while the new machines did reduce per unit production times, the pace of the workers interfacing with the new machines had slowed down. The slowdown was attributed to the need for the workers to learn their new role in the revised process. It was hoped that the worker related production times would come down as the workers learned their new roles. Figure 7 depicts the impact of the process change on the cost per unit of the 42 inch televisions. As in earlier examples, the exact magnitude of the cost increases or decreases and even the timing of these is best left to *ex post* analysis.

FIGURE 7
POST PROCESS CHANGE



CONCLUSION

In the above cases it was observed that the impact of disruptive events on a production process was best evaluated after the fact. Despite the desire to forecast the cost implications of such events, the complex nature of the man-machine interface makes reliability of such forecasts highly unlikely. A proper analysis of the impact of disruptions, product design modifications or process improvements on the underlying manufacturing costs requires a methodical analysis utilizing the concept of the learning effect, or contrarily, the forgetting effect.

In some cases it becomes necessary to break the production process down into the underlying tasks in order to properly modify the cost of these tasks, or even their inherent rates of learning. In other cases, the entire process might regress to earlier (higher) costs due to forgetting taking place over some period of time, or due to new tasks being introduced in which the worker has had little to no experience.

Businesses often find themselves the victim of change, whether self-imposed or caused by competitive necessity. Having a proper understanding of the relationships between independent and dependent variables affecting future costs is essential.

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