

Evaluating the Cumulative Impact of Changes on Labor Productivity —an Evolving Discussion

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ABSTRACT: This article presents the results of a meta-analysis of two studies and shows in quantitative terms that increasing amounts of project change will have significant impact on labor productivity. The result is a series of curves that can be used as guidelines for both estimating labor productivity before and after change event(s). Two standards have emerged from work by Charles A. Leonard in 1988, and by William Ibbs in 1995, 1997, and 2005. Compiled from research studies of actual construction projects, these studies developed a statistical relationships between the amount of change and end-of-project labor productivity. Though not perfect, they are more impartial, clearly defined, and easier to use.

KEY WORDS: Change orders, construction, labor productivity, overtime, projects, and standards

Changes on a construction project are commonplace, despite the fact that contractors often sign fixed price contracts. This may be due in part to the fact that the owners often have a unilateral right in the contract to impose such change. Reasons for changes may include new requirements, design errors and omissions, inadequate contract documents, and differing site conditions, to name a few.

Almost every change to a construction project has some effect on the project's cost and schedule. There are generally two categories of this effect:

- The actual direct cost and time of performing the change (additional labor, materials, equipment). And,
- The impact the change may have on other unchanged or contractual work because of delay, disruption, change of sequence, lack of resources, etc.

Contractors generally do not have much difficulty estimating the direct costs or time required to perform a single change, but it is very difficult to accurately estimate the impact of that change on the unchanged or contractual part of the work. To execute a change it may be necessary to disrupt or delay the unchanged work, or perform it in a manner or sequence different to that originally planned, all of which may lead to a loss of productivity and increased costs.

Difficulty in estimating the impacts, coupled with the resistance on the part of

the owner to recognize such impacts, often leads to a decision to leave impacts out of a change order. Neglecting impacts may not be a big problem if the number and value of the changes on a project is minimal, but the situation becomes much more complex in the case of hundreds if not thousands of changes on a large project.

When numerous changes occur, there is a compounding and negative effect commonly called "cumulative impact." This impact is poorly understood, difficult to measure, and seldom reflected in the sum of the estimated costs of individual project changes. The additional or changed work is often executed by means such as short-term hiring, overtime and double shifts. There can be disruptions and delays, loss of learning, trade stacking, material sourcing problems, low morale, all of which lead to significantly lower levels of productivity.

This compounding and negative effect often goes unnoticed until it is too late. It generally becomes apparent only in the latter stages of a project when work cannot be completed on time and when labor productivity does not measure up to the anticipated levels.

The difference between actual hours and estimated hours cannot, however, be explained simply by the number of approved change order hours. The balance represents unexplained extra hours which may partly be the result of an underestimate, the contractor's own inefficiencies, or, in the case of a project

suffering a multitude of changes, the loss may be the impact of the change orders.

Most project managers, when looking at an individual change, also tend to be optimistic about their ability to incorporate the change without otherwise disrupting the project. When pricing numerous changes, the contractor fails to foresee, and the owner fails to acknowledge, that the impact on the project as a whole may be greater than the sum of the hours worked on the individual changes. Furthermore, because of pressure from owners and their agents, project managers will allow late changes to be introduced, even on projects that are trending behind schedule or over budget, further aggravating the situation. The later a change occurs on a project, the less efficiently it is implemented.

Determining the impacts that changes can have on contract price and time can be arduous. As a result, it is difficult for owners and contractors to agree on equitable adjustments, especially for cumulative impact. Consequently, projects that have suffered a multitude of changes and exceed cost or schedule targets are likely to lead to cumulative impact disputes. A simple method for estimating the possible impact would be invaluable.

EVALUATING THE IMPACT

Owners frequently think that contractors make money on changes because their estimates are too high. In reality, contractors often lose money on multiple changes because their estimates are too low and because they underestimate the administrative effort required to negotiate and process the change. Pricing methodologies for changed work are often weak. Few contractors maintain adequate job-site records to allow evaluation of impact costs for individual change orders, let alone a multitude of change orders.

With each individual change, a contractor will estimate the work-hours required, but because of the inability of project personnel to fully anticipate the consequential effects of multiple changes, the actual final work-hours required may be much greater than originally anticipated. As the number of changes increases, the differential between estimated work-hours and actual work hours widens at an increasing rate.

Over the last 20 years, a number of studies have been published that attempt to

evaluate this impact. Two standards have emerged from early work by Charles A. Leonard in 1988 [11] and more recently by William Ibbs in 1995, 1997, and 2005 [6, 7, 8]. Compiled from research studies of actual construction projects these studies developed statistical relationships between the amount of change and end-of-project labor productivity. This article will focus primarily on these two studies, yet will also provide some comments on other methods as they relate to these studies.

Leonard Method

Leonard's work was the first published study to test for a statistical correlation between change orders and productivity [11]. Using data gathered from 90 construction disputes arising on 57 different projects while working for a claims consulting firm, he parsed the information into two different graphs, one for civil/architectural contracts and the other for electrical/mechanical work.

Figure 1 is representative, and shows three curves for his electrical/mechanical projects. The lowest curve is a linear regression for those projects in his database that were substantially affected by change orders only. The other two curves represent projects that were substantially impacted by change orders and one or more major causes of productivity loss such as inadequate scheduling and coordination, acceleration, change in work sequence, late supply of information, equipment or materials and increased complexity of work. His other diagram, which is not shown here for reasons of space, is for architectural/civil projects and also has three parallel curves.

As illustrated in figure 1, Leonard chose to illustrate the impact of the changes in terms of percent lost productivity (LOP) which is the ratio of the unproductive labor hours to the actual labor hours spent on the original contract (i.e., unchanged work). Most researchers have chosen to illustrate the impact of changes in terms of the construction productivity index (PI) defined in equation 1:

$$LOP = (1-PI) \times 100\%, \text{ where } PI = \frac{\text{earned hours}}{\text{actual hours}} \quad (\text{equation 1})$$

Figure 1 can be transformed into figure 2 for the purpose of comparing Leonard's results with other research.

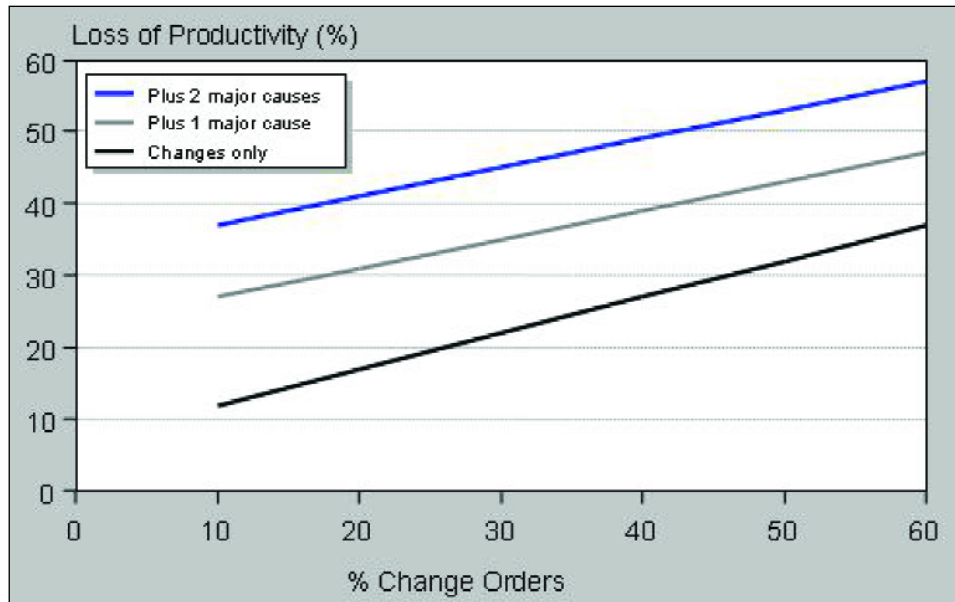


Figure 1—Impact of Changes on Mechanical and Electrical Work [11]

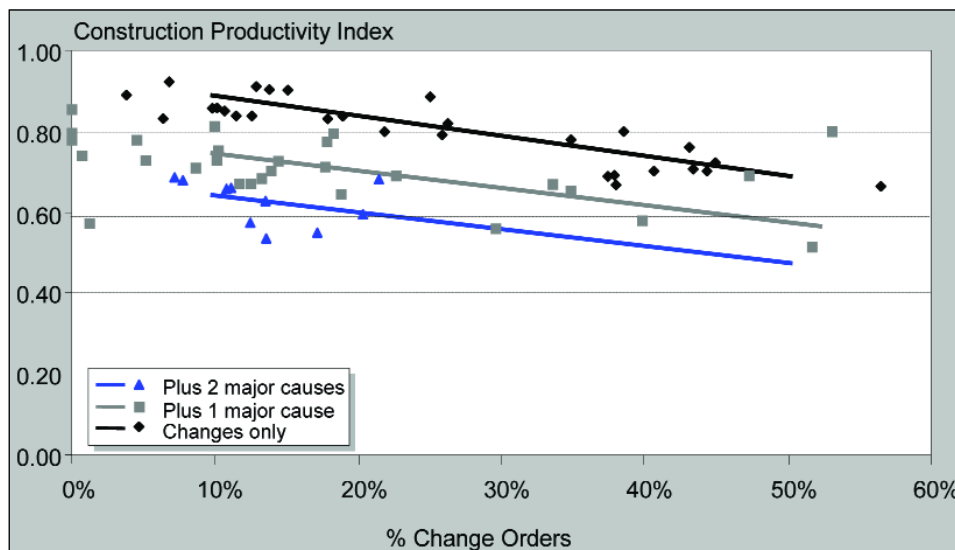


Figure 2—Leonard's Raw Data and Corresponding Regression Lines for Mechanical and Electrical Work, Illustrated in Terms of the Construction Productivity Index PI [14]

Although different in appearance, both figures 1 and 2 are basically the same since the loss of productivity is related to the productivity index as mentioned earlier. It also should be noted that figure 2 includes certain outlying data points, at values of less than 10 percent change, discarded by Leonard from his final graph. He cautioned that his results were only good for change in the 10 percent to 60 percent range.

The percent change order factor is calculated by dividing the change order labor-hours by the actual contract labor-hours. Actual contract labor-hours are defined by Leonard to be the total actual hours on the project less change order hours less any hours attributable to the contractor's own inefficiencies or bid mistakes, see equation 2.

$$\text{Percent change orders} = \frac{\text{change order labor-hours}}{\text{total actual labor-hours} - \text{change order hours} - \text{contractor mistakes}} \quad (\text{equation 2})$$

As an example calculation, consider a case where the normal or earned number of hours required for a project was determined to be 10,000 hours but that 20,000 hours were actually spent, including 6,000 hours worked and paid on change orders. Assuming for simplicity that no inefficiency hours could be directly attributed to the contractor alone, removing the change order hours leaves 14,000 hours actually worked on the base contract (including any loss of productivity because of the changes).

The “percent change orders” is 43 percent (6,000 change order hours ÷ 14,000 actual base contract hours). The productivity index is 0.71 (10,000 earned hours ÷ 14,000 actual hours) and the loss of productivity is 29 percent. As such, 4,000 hours were lost productivity out of a total of 14,000 hours actually worked on the base contract.

Although often referred to in contractor claims and in the literature, the Leonard work has not been universally accepted. One common criticism is that the research analyzed only projects that had already reached the dispute stage, which quite likely resulted in loss of productivity curves that were skewed to the “more disturbed” end of the spectrum.

None of his six curves extend to PI > 1 for zero percent change, which is not reasonable. Other voiced objections include a small data set (only 57 projects), a small (\$4 million) average project size, and the fact that all his projects were Canadian.

Additional criticisms of the Leonard method can be found under Gerald McEniry, William Ibbs and Dr. K.M.J. Harmon and B. Cole [5, 8, 14]. Nevertheless, the principal author of the present article has used both Leonard and Ibbs data in trial, arbitration, and mediation settings.

Ibbs Studies (1995 and 2005)

Working with both owners and contractors, Ibbs has collected data from 170 projects for the past 12 years [6, 7, 8]. Projects include both public and private projects with different project delivery systems, and range in size from \$2 million to \$14 billion with a median value of \$44 million.

All project data (e.g., productivity, actual project hours, change orders, contractor errors, etc.) were obtained directly from one of the project principals. Though that database includes change and productivity information for both the design and construction phases of projects, only the construction information will be discussed here.

The 1995 study contained 104 projects but has grown over time. It reported that no meaningful change - productivity differences existed for architectural / civil vs. electrical / mechanical projects, so no distinction is made here.

Contrary to Leonard’s study, several projects were found where productivity

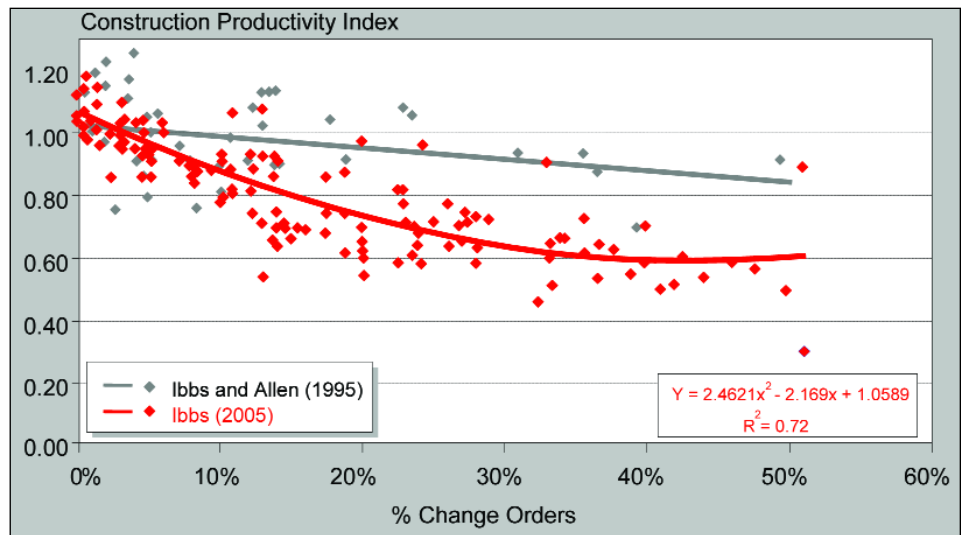


Figure 3— Comparison of the Ibbs 1995 and the 2005a Data and Curves [14]

exceeded plan (PI > 1). On the other hand, projects affected by > 25 percent change orders were so sparse, that the alignment of an extrapolated trend line could be dramatically affected by a few distant points. The 2005 study collected many more data points in the range of 20 -50 percent change orders, as illustrated in figure 3:

An examination of the Leonard and Ibbs data led McEniry to suggest that the data might be compatible in certain ranges of percent change orders [8, 11, 14]. In order to address that question though, the Leonard and Ibbs studies had to be modified so that the percent of change orders was calculated in the same way.

For this article, Ibbs’s change order percentages have been adjusted to conform to Leonard’s definition (see equation 2). The following section compares the two studies.

Leonard and Ibbs Studies Compared

Because there was no discernable difference between electrical/mechanical and architectural/civil projects in the Ibbs study, Leonard’s source data was combined into one data set. The results are displayed in figure 4.

The combined set of data show a pronounced downward sloping curve, indicating that as a project’s change increases, labor productivity will decline.

The best-fit equation is shown to be:

$$PI = 1.6911 * change^2 - 1.5442 * change + 0.9697$$

(equation 3)

R2 = 0.4951, indicating a reasonable fit.

Combining Leonard’s two sets of data results in a curve that predicts that the productivity index is never greater than 1.0. That is, for zero change, the PI = 0.9697. This is due mainly to Leonard’s data, as can be seen in figure 4 where the two sets of data are contrasted.

In this figure, the diamonds and linear curve represent Leonard’s data and the squares and exponential curve represent Ibbs’s data. Both show a downward sloping behavior, meaning that productivity decreases as change increases. Ibbs’s data shows a sharper loss of productivity and also shows that for small amounts of change positive PI values exist.

The two models give reasonably similar results for high levels of change. For example, at 40 percent change, Leonard predicts 29 percent productivity loss and Ibbs, 27 percent. At 50 percent change, Leonard predicts 30 percent and Ibbs, 34 percent.

The Ibbs study has a higher R2 value (0.563 vs. 0.0668 for Leonard), meaning it is a much better predictor. Indeed, the Ibbs data by itself has a higher R2 than the combined data set, because the Leonard data by itself is so scattered.

The fact that Leonard’s results show more negative impact for low values of change (< 20 percent) is understandable since most of his projects had already reached the dispute stage. The Ibbs curve demonstrates more positive results in this range since data was obtained from many projects seemingly unaffected by changes. The fact that both studies demonstrate significant impact for high amounts of change is also logical since any project

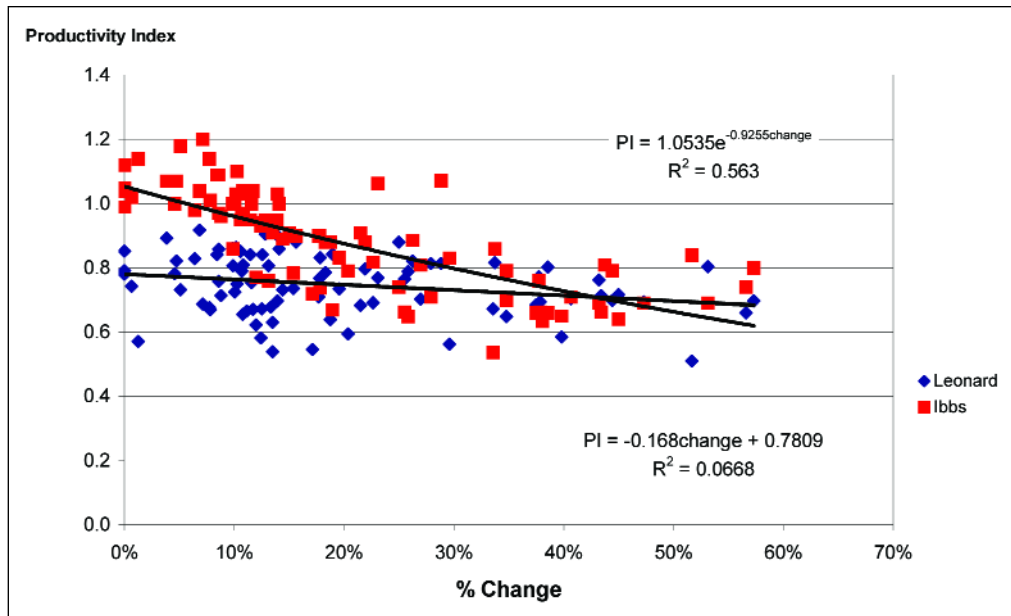


Figure 4—Comparison of the Leonard and Ibbs Data

encountering 30 to 60 percent change will be severely impacted.

Timing of Changes

The 2005 Ibbs study also explored the impact of change's timing [8, 9]. Illustrative of that later study is the graph presented in figure 5. The formulas on this figure represent the regression equation for each of the three conditions: late, normal, and early change. The R2 value is a measure of the curve's fit to the underlying project data; R2 = 1.0 would be a perfect fit.

The analysis shows that projects with late change are much more disruptive to productivity than projects where change is recognized earlier; e.g. at 10 percent change, the late curve has a 20 percent productivity loss while the normal curve has a 10 percent loss. Moreover, early and normal projects that have small amounts of change (less than 4 percent) may still have $PI > 1$ whereas these late change projects always had $PI < 1$.

"Early," "normal," and "late" were defined by rank ordering and dividing the projects into thirds. As a short-hand descriptor, early projects had 50 percent of their change recognized by 20 percent project complete; normal projects, 40 percent complete; and late projects, 70 percent.

The reader should remember that the PI is end-of-project productivity, so a project that suffers much late change is incurring more disruption and loss of productivity than meets the eye at first glance.

Leonard's thesis does not report change timing information so no direct comparison could be made with Ibbs's timing results. Nor does Leonard's data contain design phase information, so no comparison between the two studies could be made for just the design phase or the combined design-construction phases.

In 2005, O. Moselhi, T. Assem and El-Rayes presented a study conducted primarily to extend the model presented earlier by Moselhi, Charles Leonard and Fazio in 1991, to include the timing effect of change orders [16, 17]. They introduced a neural network model based on their analysis of 33 work packages extracted from files for construction projects in Canada and the US. Contrary to the linear increase in the timing factor proposed by Hanna, Moselhi modeled the build-up and rundown of labor hours normally spent to perform the work. The model was incorporated into a prototype software system to estimate the loss of productivity. In addition to the developed neural network model, the software incorporates four other models including that of Hanna 1999 [3, 4]. The authors report that their model provides more accurate estimates of change order impacts on productivity. Unfortunately, no mention is made in the article regarding how to obtain access to their prototype software.

Other Methods to Evaluate Cumulative Impact

A number of other methods have been proposed or revised in recent publications.

A detailed review of these methods is provided in William Ibbs, Long D. Nguyen and Seulkee Lee [10], William Schwartzkopf [19 and updates] as well as in the AACE International (2004) **Recommended Practice 25R-03** [1, 10, 19 and updates]. A few words are provided herein about some of the more well known methods, specifically in regards to the present study of the Ibbs and Leonard curves.

In 2005, the Mechanical Contractors Association revised one of their popular documents "*Changes, Overtime and Productivity*" including explanations on how to properly use 16 "factors affecting labor productivity" [15]. Although these factors are frequently used to estimate specific inefficiencies such as overtime, over manning etc. Richard J. Long suggests that some of the MCAA factors can also be used to quantify the cumulative impact of changes separate from the other inefficiencies [12]. He indicates for example, that the MCAA factor "morale and attitude" can be caused by "multiple contract changes and rework"; "Reassignment of workers" can be caused by "unexpected, excessive changes;" and "dilution of supervision" caused when supervision is diverted to "analyses and plan change" or "stop and re-plan affected work."

Of all the current methods, the MCAA factors are the easiest to use, which undoubtedly explains their popularity. However, the arbitrary and subjective nature of these factors undermines their credibility. In fact, even the MCAA notes

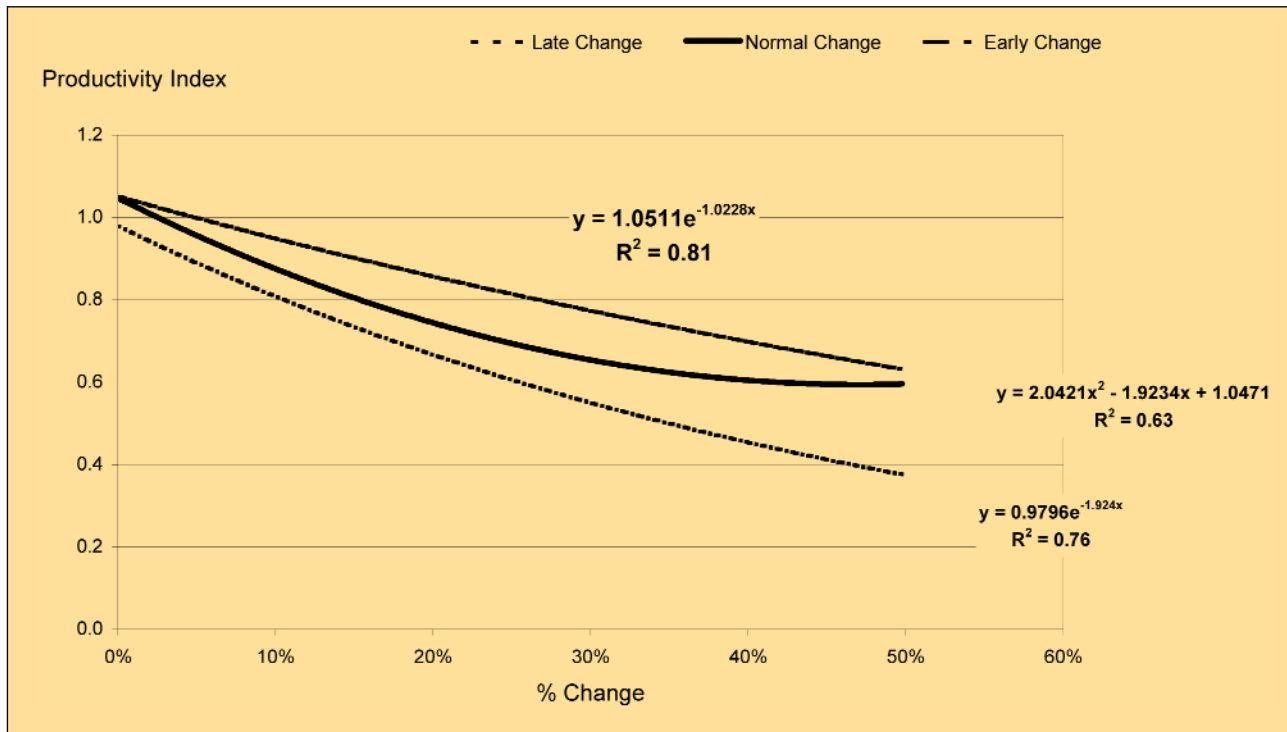


Figure 5—Timing of Changes [8]

that factors should be applied with care since the addition of multiple factors can lead to unreliable results.

For instance, application of 'severe' levels of impact for all 16 factors could lead to a 43 percent loss of productivity, which is probably not credible. Nonetheless, courts and boards in the US seem to accept the use of the MCAA factors if supported by the testimony of an experienced construction professional, who has become thoroughly familiar with the details of the specific project. Dr. K.M.J. Harmon and B. Cole summarize numerous cases where the MCAA factors were used [5].

In 1999, A.S. Hanna published two papers on the impact of change orders on productivity. The first study (1999a) [4] concerned mechanical construction and the second (1999b) [3] electrical construction. These studies found that percent change, calculated as change order hours divided by estimated base contract hours, was more significant than the "percent change" determined by Leonard and Ibbs (change order hours divided by actual base contract hours). Also, the calculation of productivity lost was based on a multi variable empirical formula not readily appreciated by contractors.

Considering the difference in the way the percentage change is measured and the many other variables involved in the calculation, the results of Hanna's studies cannot be easily compared with the Ibbs and Leonard data, at least not in a graphical format. It is understood that these studies have also not been endorsed in the US case law or board decisions published to date, according to Dr. K.M.J. Harmon and Cole [5].

Finally, AACE International recommends that productivity losses be quantified using project specific studies and contemporaneous project records, particularly the "measured mile" approach [1]. The authors agree wholeheartedly with this recommendation. In fact, the "measured mile" approach was used where possible to establish the project specific productivity loss.

CAUSATION AND ENTITLEMENT

A large number of change orders do not guarantee the contractor the right to a cumulative impact claim [18]. It is simply not sufficient to label an apparent productivity loss as the consequence of multiple changes. Many cumulative impact claims fail because the claimants do not establish a proper causal link between the changes and the lost productivity.

Productivity can be lost for numerous other reasons for which the owner has no responsibility including contractor underestimating and inefficiencies (poor planning and organization), weather conditions, etc.

In order to put forward a claim for cumulative impact, a contractor must demonstrate that there is a causal link between the lost productivity and the changes affecting the contract work. Some ways to do this include the development of a cause and effect matrix [12], or a measured mile analysis qualified with details of the changes. It is also necessary to demonstrate entitlement by proving that while individual change orders were being completed, the cumulative impact was either not foreseeable, not quantifiable, otherwise not included or not allowed when pricing the individual change orders.

SYNERGISTIC EFFECT

Certain recent publications by Bob McCally [13] and Pat Galloway [2] refer to a "synergistic effect" of changes with respect to cumulative impact. They make reference to the 1990's definition as set forth in the Construction Industry Institute's "Quantifying the Cumulative Impact of Change Orders for Electrical and Mechanical Contractors" which offers this definition:

"The theory of cumulative impact claims holds that the contractor fails to foresee the 'synergistic effect' of changes on the

work as a whole when pricing individual changes, and thereby receives less than full compensation.”

According to this theory of cumulative impact, the issuance of a multitude of change orders creates disruption that exceeds the disruption caused by the individual change orders when viewed independently. In this sense, cumulative impact would be synergistic. A contractor cannot reasonably be expected to foresee a synergistic effect when it cannot foresee the number or size of the changes to come.

McCally [13] furthermore indicates that only the unforeseeable and unquantifiable impacts can be considered as pure cumulative impact. While this limited definition of cumulative impact may be the ultimate goal for researchers and claims analysts to establish, the fact is that it is very difficult to isolate this limited synergistic effect.

Although the language of most contract clauses today requires that the contractor include all direct and indirect costs in the approved change order, in fact this is rarely the case. Many owners refuse to include the estimated cost of the impacts in change orders and many contractors reserve their right to claim impact costs at a later time when such impacts are known. As a result, the total approved change order hours reflect only direct hours and rarely include the individual impacts—even though some of the impacts may have been foreseeable and quantifiable at the time of the change order.

At the end of the project the contractor may be confronted with the situation of having a large number of excess hours worked that cannot be explained by approved change orders or even contractor inefficiencies (if admitted). The unexplained hours are pooled into what is more commonly labeled today as a “cumulative impact claim.”

In addition to the pure synergistic effect, the more common cumulative impact claim of today might include underestimated direct work hours and foreseeable impacts hours that could have, or should have been allocated to individual changes and removed from the pool. There is also a possibility that pooled hours might include hours for disputed changes (i.e., not in the approved change order total) that should also have been removed from the claim and treated separately.

In this research, both Leonard and Ibbs have attempted to remove extraneous hours related to contractor inefficiency, underestimating and disputed changes from their calculation of lost productivity, wherever these hours were identifiable.

Best efforts have been made to establish an appropriate measure of cumulative impact. It was however necessary to assume that approved change order hours include foreseeable and quantifiable impacts for individual changes (if any).

Cumulative impact is not just a theoretical concept but a real occurrence on construction projects suffering numerous changes, the impact of which is difficult to recognize as individual change orders are issued and priced. This is a result of difficulties in quantifying and pricing the impacts and also resistance on the part of owners to recognize such impacts in the change order.

This article combined the work of two notable studies by Ibbs and Leonard to quantitatively measure the impact project change actually had on construction labor productivity. The results of this comparison clearly demonstrate that increasing amounts of project

change will have significant and progressively worsening impact on labor productivity.

The curves presented in this article can be used as guidelines in evaluating the cumulative impact of multiple changes on labor productivity. The curves stem from actual project records, are impartial and are easy to use. Though not perfect, the trends seem logical. These curves should not be considered a complete solution to the dilemma of evaluating the cumulative impact of changes. Research is constantly evolving, and more cases should be analysed and discussed to confirm the results. Alternative methods should be used to corroborate any results.

Naturally it is best if change can be identified, measured, and evaluated on a case-by-case basis, according to Ibbs, Nguyen, Lee [10]. In those situations the impact is easier to evaluate and negotiate, whether it is through a time-and-material or forward pricing mechanism. Most importantly, the possible impact should not be ignored. However, when many changes start to accumulate and even interact with each, evaluation and resolution are more difficult. Generally, a measured mile approach is preferred, but there are many times when no measured mile can be obtained.

In such cases, an approach like that presented in this article may be helpful. Though specificity is always preferred, general industry statistics can be corroborative in the hands of an impartial change expert. Just like generalized test scores are used to admit students to college (SATs) or law school (LSATs), generalized industry statistics like the Leonard and Ibbs curves have value in estimating change’s impact on labor productivity.

Of course it is important to use models like these judiciously. For instance, a contractor’s actual project experiences must be adjusted for bid mistakes and other inefficiencies. In addition, hours associated with disputed changes, or foreseeable impacts that could have been allocated to individual changes, should be removed and treated separate from the cumulative impact. Causation and liability of change must also be fully demonstrated in order to be compensated.

Still, if proper adjustments are made and these studies are applied impartially, information like that presented herein can be quite useful, whether predicatively with each change order in an effort to reduce cumulative impact, or later in a more global fashion to resolve disputes. The fact that the principal author of this article has used his study in actual litigation demonstrates that this type of research can be useful to the construction industry. ♦

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