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The Cumulative Effect of Change Orders on Labour Productivity – the Leonard Study "Reloaded"

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Introduction

Some twenty years ago, we published a Revay Report entitled "The Effect of Change Orders on Productivity"[1] written by Charles Leonard, who at that time was a consultant at our firm completing his Master's thesis in Construction Management at Concordia University in Montreal[2,3].

In the ensuing years, the Leonard study stirred much interest and controversy amongst contractors and owners involved in construction dispute resolution. An internet search will confirm a multitude of references to the Leonard study in conferences, industry publications and research papers. Revay and Associates Limited is pleased to have been at the forefront of such important research and we continue to follow developments in this area.

In the same vein, you may recall our more recent (September 2002) Revay Report[4] entitled "Coping with Extras" which reviewed criticism of the Leonard study and other prominent research on the subject, most notably by Ibbs and Allen in 1995 (under the auspices of the Construction Industry Institute)[5] and by Hanna et al in 1999[6,7].

In November 2005, Ibbs added the results of more extensive research to his 1995 study in a new publication[8] that significantly modifies the conclusions of his initial analysis and which, in our opinion, revitalizes the early work done by Leonard. Additionally, in his new study, Ibbs discusses the issue of the timing of changes, also a hot topic in the assessment of the cumulative impact of changes. In our continuing effort to keep you, our clients, informed of such recent research, we thought it opportune to revisit the evolving discussion of the impact of changes on labour productivity and at the same time "reload" the Leonard study.

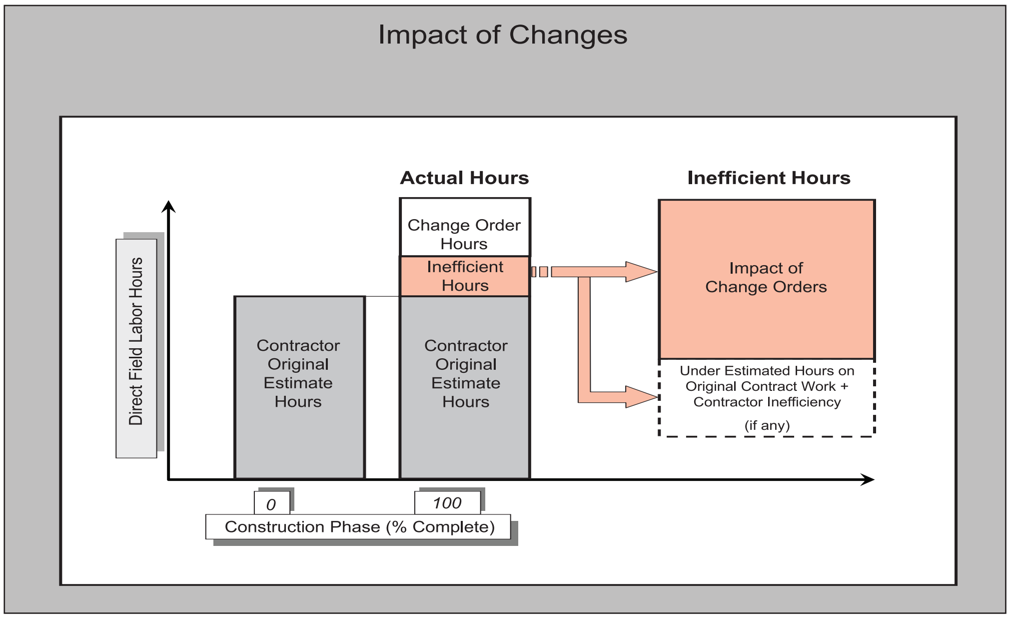

Figure 1 – Impact of changes (adapted from Hanna 1999)

Leonard Study (1988)

In 1988, the Leonard study was a pioneering attempt to determine the cumulative impact of multiple changes on construction labour productivity. It was based on 90 construction disputes occurring on 57 different projects that had been evaluated by our firm. The projects involved the construction of a variety of commercial and institutional buildings as well as industrial plants.

According to Leonard the cumulative impact of the change orders can be defined as:

> Generally delays and disruptions caused by change orders were found to bring about gradual deterioration of the contractor's planning and scheduling. Orderly sequences of operations were divided into several, perhaps isolated, activities completed in piecemeal fashion over an extended period.

The impact of the changes is manifested through productivity related issues that result from factors such as re-sequencing of work, trade stacking, overtime, material sourcing problems, weather conditions, labour problems, low morale, shift work and the need for schedule compression (acceleration).

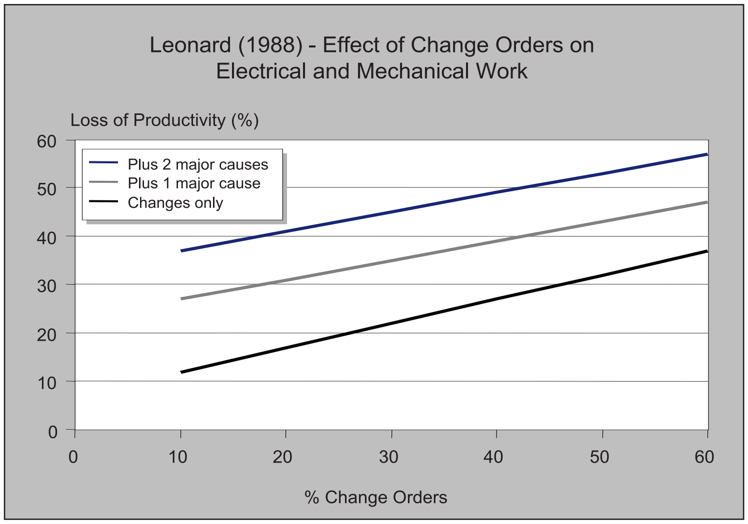

Figure 2 – Impact of Changes on Mechanical and Electrical Work (Leonard 1988)

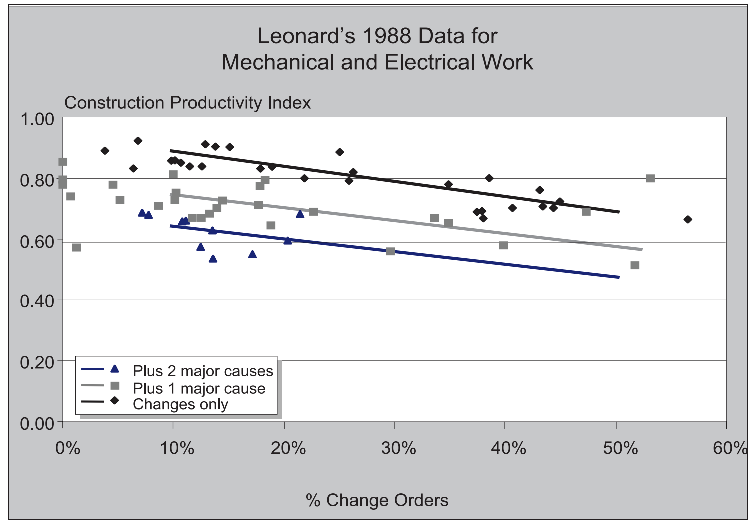

Figure 3 – Leonard's raw data and corresponding regression lines for mechanical and electrical work (Leonard 1988)

The results of Leonard's research are often depicted in two graphs, one for civil and architectural work and the other for electrical and mechanical work, of which only the latter is illustrated as Figure 2.

It is important to understand for later discussion that, in his study, Leonard measured the "percent change orders" (represented by the x-axis) in terms of the sum of change order hours divided by "actual" hours spent on the original contract (i.e. unchanged) work. Actual contract hours were not the estimated base contract hours, but rather the total actual hours less change order hours less any hours attributable to contractor's own inefficiencies. The actual hours, therefore, inherently included the impact of the change orders on the original contract (i.e. unchanged) work, as depicted in Figure 1.

Leonard calculated the loss of productivity using the differential method of calculation ("measured mile") whenever possible. He first determined the "normal" hours from which the lost hours could then be established. In cases where the normal hours could not be determined, "earned" hours (which could be equated to normal hours) were used to calculate the lost hours. If the contractor's estimate was considered reasonable, then earned hours were the estimated (budgeted) hours. If the contractor's estimate was not reasonable, the earned hours were modified to put them in line with other bids.

Leonard then calculated the productivity index ("PI") as the ratio of earned hours vs. actual base contract hours. Loss of productivity ("LOP") was calculated as follows:

$$\text{LOP} = (1 - \text{PI}) \times 100\%$$

Loss of productivity was also the ratio of the unproductive labour hours to the actual labour hours spent on the original contract (i.e. unchanged) work. Loss of productivity and the productivity index were illustrated on the y-axis.

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

As mentioned earlier, Leonard made a distinction between civil/architectural work and mechanical/electrical work. He also established differing levels of impact based on the effect of changes only, or changes plus either one or two major causes (Figure 2). Leonard described these so-called "major causes" as acceleration, out of sequence work, over stacking of trades, lack of materials, etc. It now appears that some of these so-called "major causes" may often be the impact of the changes themselves and that the distinction of results into separate levels of impact is not a simple task.

Figure 3 illustrates, in a slightly different format from Figure 2, the raw data for mechanical and electrical work as well as the corresponding regression lines established by Leonard. It also should be noted that Figure 3 includes certain outlying data points, at values of less than 10% change, discarded by Leonard from his final graph.

Although different in appearance, both Figures 2 and 3 are equivalent since the loss of productivity is related to the productivity index as mentioned before:

$$\text{LOP} = (1 - \text{PI}) \times 100\ \%,$$

where PI = earned hours ÷ actual base contract hours

Most researchers have chosen the construction productivity index as the indicator of lost productivity and we will continue with this form of graphical presentation.

Once differentiated by major cause, the Leonard analysis indicated a high correlation between the percentage change order hours to contract hours and the loss of productivity. However, this distinctive approach, with three significantly different trend lines, was not generally adopted by other researchers who have preferred to group all data together and attempt to explain the scatter in the data as the result of other factors.

Criticism of the Leonard Study

Over the years, the Leonard curves have been the subject of considerable discussion and criticism. Although most would agree with his overall conclusion that numerous changes impact productivity, serious objections have been raised with regard to the data used to quantify the productivity loss. The most common criticism lies with the fact that the research was developed using cases that had reached the dispute stage, which may introduce a bias towards projects suffering important productivity losses. Some consider that the size and number of the projects studied were too small and insufficient to extrapolate to the industry as a whole[6,7].

Other limitations and criticism of the study include the fact that the study cannot be used to predict loss of productivity when change order hours are less than 10% of the original contract hours, that the study does not address the issue of the timing of the changes[6,7], that other factors, such as the weather, labour conditions and code requirements, are particular to the Canadian industry and not necessarily representative of the American industry[8].

In a September 2006 article[9], authors Harmon and Cole disagreed with some of these criticisms but point out that no published court decisions in the U.S. or Canada indicate that the Leonard approach has been accepted in predicting the cumulative loss of productivity. This article referred to one published opinion discussing the Leonard study (Appeals of J.A. Jones Const. Co)[10] where the method was rejected by the Board of Contract Appeals as being inapplicable to heavy civil engineering construction projects and suggested that the so called expert testifying about the study was apparently unfamiliar with its details and limitations, which ultimately led to it being abandoned.

We have noted over the years that the Leonard study has been similarly misunderstood and misused by contractors attracted by the simplicity of the graphs but also unfamiliar with the details of the study and limitations to its use. For instance, some contractors:

• Make no effort to use the differential or measured mile method where possible, contrary to Leonard's recommendation[2]. Contractors use the Leonard study as a substitute for project-specific analysis.

• Attribute all overrun in hours as being the result of owner caused changes and make no adjustments for other factors such as estimating errors or contractor inefficiency.

• Miscalculate "percent change orders" as:

- a function of the dollar value of changes instead of hours,
- a portion of estimated hours rather than actual base contract hours.

• Fail to demonstrate a cause and effect link between the alleged inefficiency and the change (for example see Long 2005[11], Ibbs 2007[12]). Although this may be a subjective exercise, it is vital to establish entitlement. Other factors not related to owner directed changes (weather, project conditions, union problems, delays) could be responsible for the lost productivity on a construction project.

These misuses persist, notwithstanding Leonard's instructions to the contrary, and have no doubt contributed to the criticism of the study.

The root cause of lost productivity is frequently a matter in dispute between owners, contractors and subcontractors. Owners often blame a bad bid or the contractor's poor management and deny compensation for the alleged lost productivity due to changes.

Ibbs and Allen (Construction Industry Institute) 1995

In 1995, Ibbs and Allen, working under the auspices of the Construction Industry Institute, studied some 104 projects from 35 different companies (15 contractors and 20 owners) representing both disputed and undisputed projects, foreign and domestic work, industrial, commercial and heavy civil work, and various delivery systems. These were rather large projects, as the median value of the projects was $44 million.

Ibbs and Allen published Figure 4 illustrating the relationship between the construction productivity ratio and construction change.

Ibbs and Allen did not make a distinction between the project data points on the basis of type of project (architectural/civil or electrical/mechanical) nor was any distinction made for other major causes as was the case in the Leonard study. One wonders if some of the scatter in the data points seen in Figure 4 might be explained by the type of project or other causes.

The Ibbs and Allen (1995) study presented a significantly more optimistic, or less severe, estimate of lost productivity than Leonard. For example:

• The Leonard curves do not extend into the area where changes are less than 10% whereas the Ibbs and Allen results indicate that, in cases where changes on a project are less than 10%, productivity could in fact be even better than estimated.

• At 50% change, the Leonard curve for civil and architectural work would indicate a minimum loss of productivity of about 25% (changes only) while the Leonard curve for mechanical and electrical work would indicate a minimum loss of productivity of about 32%. The Ibbs and Allen curve, however, indicates a loss of productivity of only 15% regardless of the type of project.

For many years, the Ibbs and Allen (1995) study cast serious doubts on the application of the Leonard curves to projects other than those studied by Leonard.

Having said this, it should be noted that there may be a significant difference between the way Ibbs and Allen (1995) and Leonard (1988) measure the "percent change orders". The Ibbs and Allen document states:

> The "percent change" is defined as the number of work-hours expended on authorized changes that originated during the construction phase divided by the total number of work-hours expended for construction.

The importance of such a difference in the way the "percent change orders" is measured will be discussed later in this article. Ibbs does not indicate (as Leonard did) that the denominator in this case excludes the change order hours, although it would be logical to have done so. It also seems uncertain whether any evaluation was done by Ibbs and Allen to adjust for contractor inefficiencies.

Criticism of the Ibbs and Allen (1995) study concerns the scatter in the data and consequent low correlation between the productivity index and the "percent change orders" as can be seen in Figure 4[6,7]; as well as the admission that the charts are "too general to be used in all circumstances to price

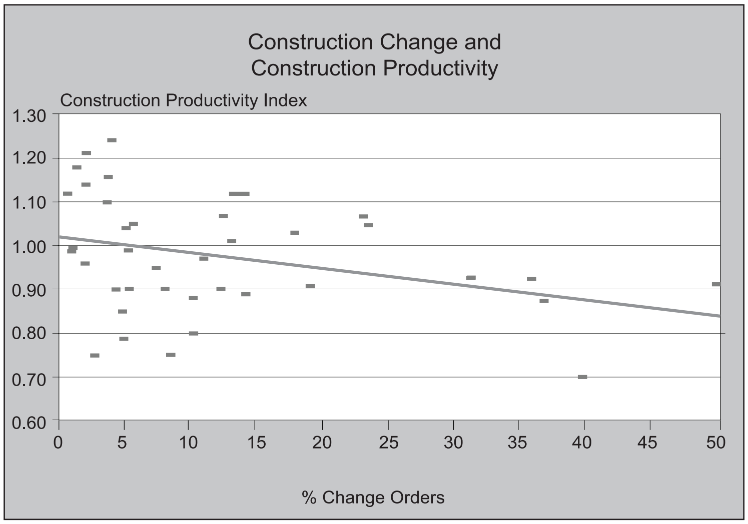

Figure 4 – Results of the Ibbs and Allen / CII study (1995)

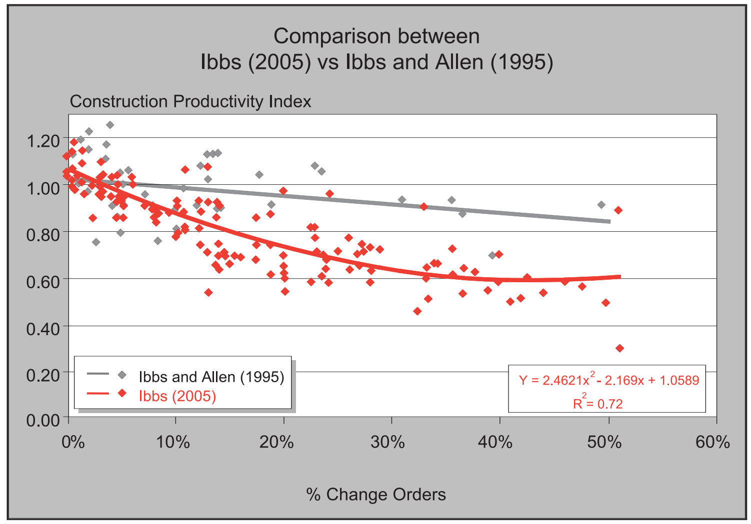

Figure 5 – Comparison of the Ibbs 1995 and 2005 data and trend lines

every individual change precisely"[5] (page 12 of his study).

This study has not yet been used or discussed in the U.S case law or board decisions[9].

Hanna 1999

In 1999, Hanna published two papers on the impact of change orders on productivity. The first study concerned mechanical construction[6] and the second electrical construction[7]. The studies were based on information obtained either from mechanical or electrical contractors working on 61 projects. Mechanical projects varied in value from $61,000 to $13,600,000. Electrical work is described in terms of hours from 1,100 to 106,000 hours.

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 (change order hours divided by actual base contract hours). Also, the calculation of productivity lost was based on a multi variable empirical formula including the following additional factors:

For mechanical construction:

IMPACT = Impact classification (subjective evaluation)

CHGEST = Change order hours / estimated base hours

NUMCHG = Number of changes (total)

WTIMING = Weighted timing factor for timing of change orders

For electrical construction:

the number of years experience of the project manager;

the estimate of change orders as a percentage of the original estimate (expressed in logarithmic units); and

the estimate of change orders expressed in logarithmic units.

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 Leonard's data, at least not in a graphical format.

Criticism of Hanna's studies includes the underlying assumption that estimates of the overall project hours and the change order hours were reliable[9]. It seems that actual change order hours used in his study were not tracked but rather estimated. The proposed relationship is also complex (see his articles for the formula) in terms of the number of variables to be evaluated (four independent variables for the electrical work and 10 for the mechanical work). It is hard to understand why the variables would be different for each trade. It also appears that some of the variables give counter intuitive results. For instance, it would seem that lost productivity would be less if the project manager spent more time on the project and over manning occurred. The ranking of the impact classification, the only variable common to both electrical and mechanical work, is considered subjective[8]. Finally, Hanna's study of mechanical work concluded that the timing of the change was significant, (i.e., the impact of changes on productivity varied depending on when the change was issued during the project life). This aspect is important and will be discussed in more detail later in this article.

It is understood that these studies have not yet been endorsed in the U.S. case law or board decisions[9] published to date.

Ibbs (2005)

In 2005, Ibbs published a paper entitled the "Impact of Change's Timing on Labour Productivity"[8]. The data were collected over nine years and included those of the 1995 study. A total of 162 disputed and non-disputed projects were studied from 93 organizations including contractors, owners, construction managers and design firms. The projects can be categorized as 35% heavy/highway, 16% commercial and 49% industrial. The projects were more or less evenly split between public sector (45%) and private sector (55%) while two thirds were delivered using the traditional method of design/bid/build. The projects varied in size between $3.9 million and $14.5 billion.

Ibbs did not classify the type of project as Leonard or Hanna had done (i.e. in terms of civil/architecture or mechanical/electrical). Ibbs found that this distinction was unnecessary as this variable did not make a significant difference in the impact of the change.

It is particularly interesting to note that many more data points were collected in the range of 20-50% changes. The original data in 1995 were so sparse in this area that a few odd points could dramatically affect the alignment of the extrapolated trend line. We have prepared a comparison

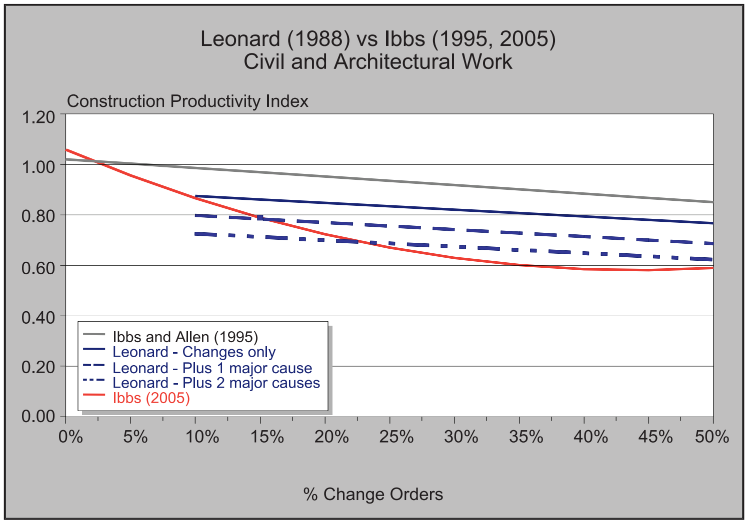

Figure 6 – Comparison of the Leonard (civil and architecture) data and trend lines with Ibbs 1995 and 2005

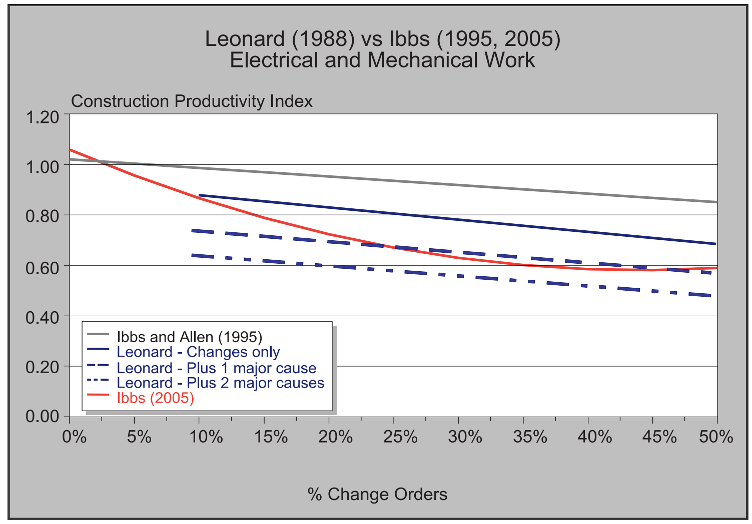

Figure 7 – Comparison of the Leonard (electrical and mechanical) data and trend lines with Ibbs 1995 and 2005

of the two Ibbs studies in Figure 5 which illustrates the dramatic difference between the 1995 and 2005 results.

As seen, the 2005 data indicate that changes had a more significant impact on productivity than the Ibbs and Allen (1995) study (i.e. as much as 20% or more).

The labour productivity for projects with no change (0%) was about 6% above planned. In other words, work was performed for fewer hours than estimated. The labour productivity of projects with 3% change was 1.00, meaning the actual rate (and number of hours worked) equalled the planned productivity. Labour productivity was affected negatively by changes in excess of 3%. This number is important because many owners believe that contractors expect and plan for as much as 10% changes and sometimes refuse to recognize any possibility that changes may impact contractors below such a level.

According to Ibbs, the relationship between changes and the productivity ratio can be illustrated by a polynomial expression as illustrated in Figure 5 with a correlation coefficient of 0.72. Ibbs indicates that the “fit” is better and that productivity is more predictable at low levels of change than at higher levels because the standard deviation is less.

Considering the significant difference between the 2005 and 1995 data and trend lines, we were curious to see how the results of the Leonard study would compare to the new trend line established by Ibbs in 2005. Assuming for the moment that values of “percent change orders” can be equated between the two methods, we plotted the results of the Leonard and Ibbs analysis together on the same graph. The results are illustrated in Figures 6 and 7. We caution the reader, however, that this assumption requires some clarification to be made later.

At first glance, it is evident that the Leonard curves fall below the Ibbs and Allen (1995) study but generally above the Ibbs (2005) study. In fact, it would appear that the Leonard curves are overall more conservative than the Ibbs (2005) curve. The “changes plus one major cause” line of the Leonard mechanical analysis resembles the Ibbs (2005) results (at least when the number of changes falls within the 20-50% range) and even underestimates the impact of changes relative to the Ibbs (2005) analysis at least when comparing the “changes only” lines to the Ibbs curve.

It is interesting to note that at “percent change” values of less than about 15-25%, for changes plus one or two major causes, the Leonard analysis appears to overestimate the loss of productivity relative to the Ibbs (2005) curve. This could be due to the fact that Leonard’s analysis was based only on disputed projects whereas the Ibbs (2005) analysis is derived from both disputed and non-disputed projects. In fact, Leonard did not extrapolate the results of his linear regression below 10%.

Also of interest to us was how the actual data points used in the Leonard analysis would compare with the data of the Ibbs (2005) analysis (see Figures 8 and 9). It should be noted that we have included all of the Leonard data, even those points with a “percent change orders” less than 10% (outside the limits recommended by Leonard).

The Leonard data points have been overlaid on a graphical image of the Ibbs data because we did not have Ibbs’ actual data. In both Figure 8 and 9, the Ibbs data points remain the same but the Leonard data points may change position depending upon how the percent change is calculated.

Figure 8 compares data points assuming the “percent change orders” is measured the same way between Leonard and Ibbs, that is:

% change = change order hours
÷ actual hours*
*(excluding change order hours)

However, as previously mentioned, a question arises as to whether Ibbs and Leonard measure the “percent change orders” the same way. We understand that Ibbs measures “percent change orders” differently, that is:

% change =
change order hours ÷ actual hours*
*(including change order hours)

In our opinion, Leonard’s method of measuring “percent change orders” is intrinsically more reasonable. Consider the previous example where 10,000 hours were determined to be the normal or earned number of hours required to do a job, but that 20,000 hours were actually required including 6,000 hours worked and paid on change orders. According to Leonard, “percent change orders” would be 43% (6,000 change order hours ÷ 14,000 base contract hours). However, according to our comprehension of the Ibbs (2005) method, the “percent change orders” would be stated as only 30% (6,000 change order hours ÷ 20,000 base contract and change order hours).

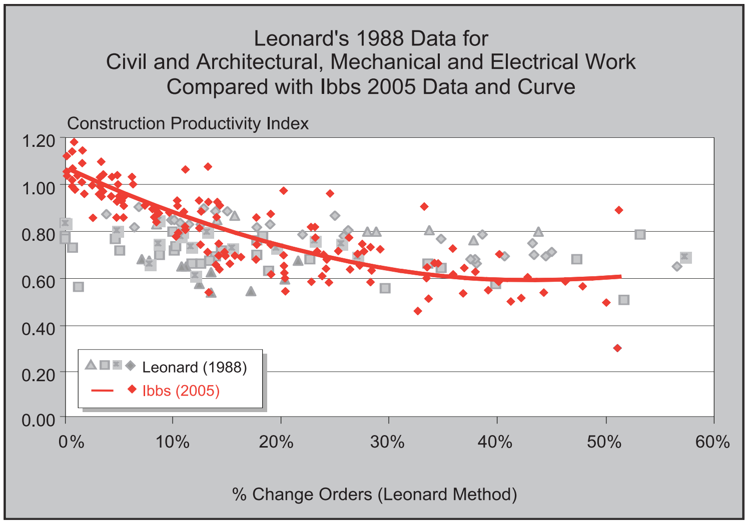

Figure 8 – Leonard unadjusted data compared with Ibbs 2005 data

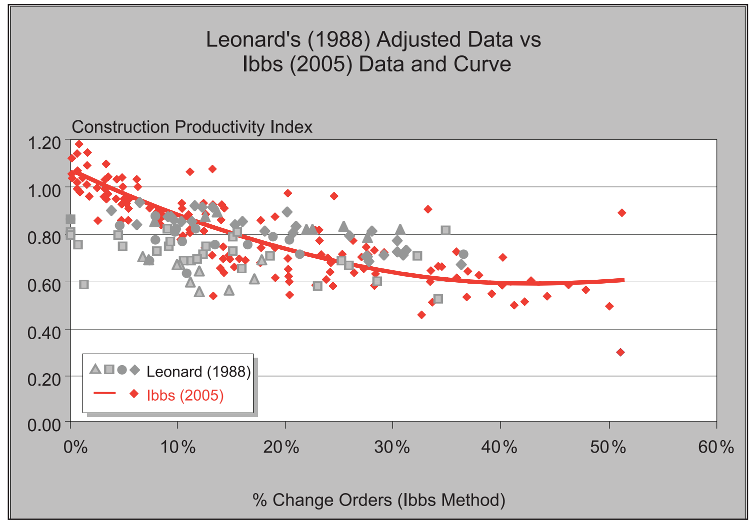

Figure 9 – Leonard adjusted data compared with Ibbs 2005 data

This calculation also highlights another problem measuring "percent change orders" and lost productivity. Typically, change order hours are hours paid for authorized extra work, while the amount of extras so authorized is dependent upon the project team's ability to have alleged extra work recognized and paid as such. Obviously, not all contractor claims for extra work will be recognized. Some of the additional hours worked may well be the result of disputed extra work and some will be the impact of the authorized changes. Practically, it may be difficult to distinguish between the two and the situation could give rise to different interpretations. For instance, on a given project there was a theoretical 30% increase in scope. One team may get paid for 40% as the increased scope while another team may get paid for only 20%. Based on these numbers the team getting paid only 20% would appear to have suffered a more significant loss of productivity considering the actual amount of unpaid work hours.

Returning to the difference between the Leonard method and Ibbs method, the effect of the difference between the way "percent change orders" is measured would be to shift the Leonard data points to the left as can be seen in Figure 9. The effect may be small at values of "percent change orders" less than 20%, however, the difference becomes much more appreciable at higher values of "percent change orders". If a similar adjustment is made to the Leonard data in Figures 6 and 7, the lines representing Leonard's major causes would become steeper, and probably reflect more closely the slope of the Ibbs curve for percent change orders less than about 35%. It is interesting to note that Thomas and Napolitan (1995)[13] remarked that the slope of the Leonard curves was shallower than they expected, suggesting that they also may have used a different method of measuring "percent change orders" than Leonard.

Despite the possible difference in the way the "percent change orders" is calculated, overall it would appear from Figures 8 and 9 that both sets of data provide results similar to Ibbs 2005. Some divergence occurs for the Leonard data points when "percent change orders" is less than 10%, apparently due to the fact the Leonard data was obtained only from impacted projects whereas the Ibbs (2005) study analyzed many projects un-impacted by small amounts of change. The Ibbs (2005) research indicates a neutral or even positive effect for projects with small amounts of changes, which we agree seems more likely. It would have been interesting to recalculate the regression polynomial but we were unable to do so because we did not have Ibbs' actual data.

Criticism of the Ibbs (2005) study

Although the Ibbs (2005) study is probably the most extensive study of its kind carried out to date, it has not yet been endorsed by the industry. Like many of the previous studies, this relatively recent research has not yet been discussed in the published U.S case law[9,14].

As research continues to evolve on this subject, the industry's focus will probably shift to discussing and testing the latest studies. Should the Ibbs (2005) study be confirmed, it could then also be implied that, for their time, the Leonard graphs were reasonable indicators of the impact of change orders would have on labour productivity (at least when changes exceed 10%).

Possible criticism of the Ibbs (2005) study might involve the two key assumptions that 1) the contractor's estimated work hours for the original work (i.e. planned productivity) and the change order work are accurate, and 2) the contractor did not mismanage his part of the work (i.e. the actual hours worked include only loss of productivity due to changes and not due to contractor inefficiencies). Ibbs admits (page 1221 of the 2005 study) that if these numbers are not accurate "then the ratio of actual to planned productivity would misstate the amount of productivity lost".

Ibbs also indicates that:

> Change is measured in absolute terms, meaning that a project that had $1 of deductive changes and $1 of additive change would be treated as having $2 of total change. The rationale is that deductive change can be disruptive to productivity, just as additive change can be. To use the net difference between additive and deductive change would understate that disruption.

We have not evaluated the consequences of this aspect of Ibbs' analysis as Leonard's work was based only on additive changes.

It must also be repeated that criticism may arise when the results of analyses such as Leonard's and Ibbs are not properly understood and applied. This may be the case when the results are applied blindly and without regard to important aspects such as the timing of the changes.

Timing of Changes

Although early research recognized that change orders occurring late in a project appeared to have more impact on productivity than change orders occurring early in the project, neither Leonard nor Ibbs and Allen (1995) were able to easily quantify the effect of the timing of the change on construction labour productivity.

As mentioned earlier in this article Hanna (1999a)[6] attempted to include a weighted timing factor into his multi-variable formula to calculate lost productivity, at least for mechanical construction. Hanna assumed that the impact of timing increases in a linear manner from project inception to completion. The evaluation of this weighting factor and the other variables in his formula is, however, a somewhat awkward process and requires certain subjective determinations.

In 2005, Moselhi, Assem and El-Rayes[15] presented a study conducted primarily to extend the model presented earlier by Moselhi and Leonard[3] in 1991 to include the timing effect of change orders. They introduced a neural network model based on their analysis of 33 work packages extracted from Revay and Associates Limited files for construction projects in Canada and the U.S. Contrary to the linear increase in the timing factor proposed by Hanna, Moselhi modeled the build-up and rundown of labour 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[6,7]. 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. This study has not yet been cited in U.S. case law.

Ibbs (2005) measured the rate at which changes were introduced in the sample projects and found that certain projects recorded change earlier than others (see Figure 1 of the Ibbs (2005) article[8]). He then ranked the projects into three categories: Early (the 25% of the projects where change was recognized fastest), Normal (middle 50%) and Late (slowest 25%) changes. He then prepared the graph reproduced in our Figure 10 showing the increase in the degree of impact the later changes are introduced.

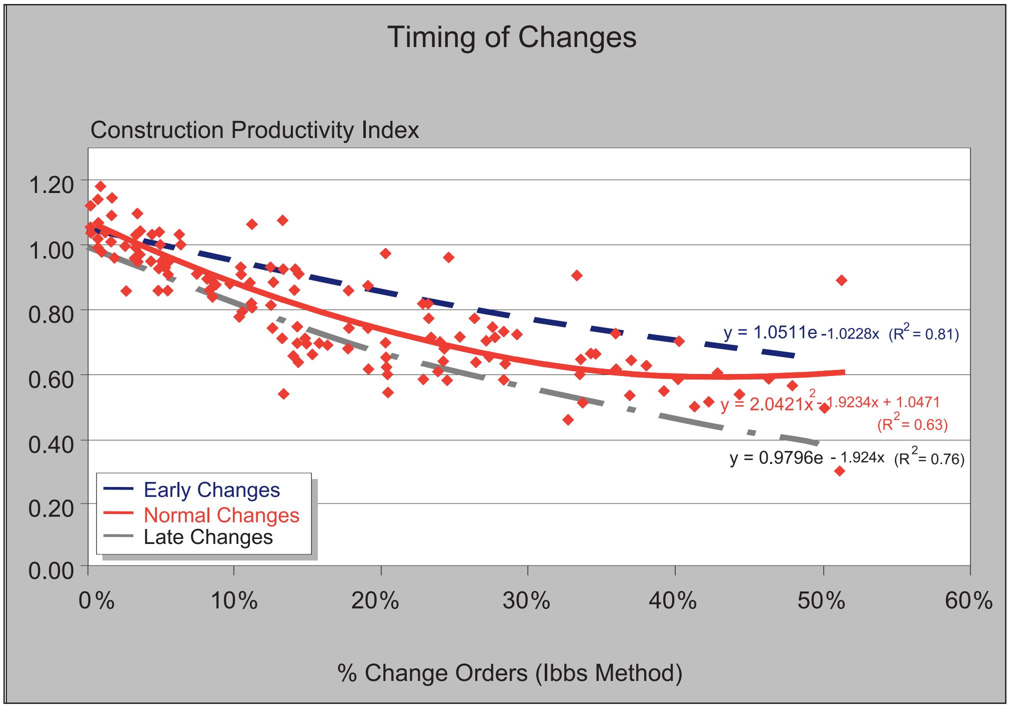

Figure 10 – Timing of Changes – adapted from Ibbs 2005

It is interesting to note the similarity between the three curves suggested by Ibbs to describe the effect of timing of the changes and the three regressions developed by Leonard to describe the effect of other "major causes". Leonard describes these causes as out of sequence work, acceleration, over manning, lack of materials, etc. Arguably, these causes are the impact of the changes themselves occurring in later stages of the project. Again the results of the Leonard study appear to agree with those of Ibbs.

Ibbs (2005) explains that projects where change is introduced "early" relative to the time of performance can accommodate a small amount of change. The above graph suggests that the limit is about 3%, after which the productivity ratio drops below 1.0. Even when larger numbers of changes occur, their early introduction lessens the negative impact.

Ibbs also states in the 2005 study:

> Late changes on the other hand, always result in a productivity ratio <1.0 (substandard) and the rate of change (the slope of the late change curve) is more pronounced than is the case for either of the two other curves. In rough terms, the late change is about twice as detrimental to productivity as normal or early change, e.g. at 10% change, the late change curves has a 20% productivity loss while the normal change curve indicates a 10% loss.

This finding is important as it demonstrates that contractors should consider the timing of changes when estimating the impact the change may have on the contract work.

Moreover, it should be realized that estimated factors of lost productivity derived from the above graphics should not be applied blindly across the whole project. An effort must be made to determine when the changes took (or will take) place and apply the estimated loss of productivity factor to the hours worked (or to be worked) in a particular period. For instance, if most changes were initiated on a specific project between 50 and 100% completion, the estimated loss of productivity should not be applied to man-hours worked before this period, unless it can be demonstrated that the changes had some detrimental effect.

The issue of timing may, however, be more difficult to resolve than portrayed in the above graphics because contractors and owners frequently proceed without the proper paperwork being in place. Ibbs uses the change notice date to establish when the change was initiated to be uniform in his study, but in our experience, it is often difficult to confirm when the change actually interrupted and impacted the work.

Conclusions and Recommendations

In its time, the Leonard study was a pioneering effort in evaluating the cumulative impact changes had on labour productivity. Despite certain limitations and significant criticism expressed over the years, in our opinion, current research by Ibbs and others supports the credibility of the study.

It must be stressed that it is not the intention of this article to recommend the Leonard, the Ibbs or any other study as a final solution to the dilemma of evaluating the cumulative impact of changes. Although the trends seem logical, research is evolving, and more analysis and discussion is required to test these methods. It should be remembered that none of these methods have been endorsed in the case law published to date[9,14].

We do recommend that each case be evaluated on its own by an experienced professional. Generic industry studies should never replace project-specific information[12,16]. Use and interpretation of any such industry study is best supported by expert analysis of the specific facts which establish causation and entitlement. Moreover, it is important to recognize that the project teams' effectiveness in managing and administering changes and other adverse productivity factors will significantly contribute to the successful execution of the project. As such, it is unrealistic to assume that any or all projects across the board will experience the results portrayed in the above graphics.

Lost productivity is best studied by evaluating causes and effects specific to a particular project and, when possible, performing differential analysis between normal and impacted periods of the work[16]. Industry studies alone are of limited use.

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