Scholarly Paper

Construction Change: Likelihood, Severity, and Impact on Productivity

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Abstract: Change on construction projects is a regular occurrence and impedes project success for both the owner and the contractor. Many papers have been written about change, but few document its prevalence, severity, and impact on labor productivity in a reliable, quantitative way. The purpose of this paper is to help project owners, contractors, and other parties understand and benchmark their projects against a large set of construction projects. Data from two independent research studies are analyzed to quantify the impact of change on project cost, schedule, and productivity. The result is a set of curves and reference points that contrast the amount and likelihood of change with the amount and nature of its impact. One major finding of this study is that the ratio of final project costs to estimated project costs is substantially higher than conventionally thought. Previous reports hold that two-thirds of all projects should have fewer than 15% change. The equivalent number found in this study was 19%. Approximately 40% of all projects in this study experienced more than 10% change. Many industry observers believe that cumulative impact is a rare condition and is likely to occur when change exceeds 10%. On the basis of these findings, cumulative impact occurs more frequently than generally thought. Two other findings concern the quantitative rates at which productivity and the predictability of productivity deteriorate with increasing amounts of change. Productivity exceeded planned rates on 60% of the projects when change was limited to 5%, but it never reached planned rates once change exceeded 20%. Minimizing change is thus important for realizing good productivity performance. Change averaged 8% on these projects. Findings presented in this paper can be used to forecast prospectively the impacts that change has on cost, schedule, and productivity. They can also help the parties retroactively assess the impact of change when looking for guidance to settle disputes. **DOI: 10.1061/(ASCE)LA.1943-4170.0000089.**

CE Database subject headings: Change orders; Costs; Scheduling; Productivity; Construction industry.

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Introduction

Change is any addition, deletion, or revision to the general scope of a contract (Ibbs 1994). It may cause an adjustment to the contract price or contract time, and it occurs regularly on construction projects. Construction change has many causes, including the uniqueness of each project and the difficulty in predicting the future. However, changes all have something in common, namely additions or deletions to the scope of work, which consequently creates rework and possibly schedule resequencing, acceleration, delay, or suspension. These events in turn may impair labor productivity. Direct labor costs of the project may then increase and slow project progress, elongating the schedule and increasing overhead costs. Total project cost may subsequently be increased, thus reducing or eliminating the contractor's profitability and impairing the owner's return on investment or project utility.

When the owner is responsible for a change, the cost and schedule impacts of change are incorporated into the original contract by way of change orders. These amendments allow the owner to alter work performed by the contractor and provide a mechanism for defining adjustments to the project's scope, price, and schedule. However, owners and contractors do not always agree on such adjustments.

The problem gets even worse if large amounts of change occur because a special condition, called cumulative impact condition, results.[1] In other words, a project loses more productivity than is captured by the sum of individual change orders.

Productivity in this paper is defined as the craft hours necessary to produce a unit of finished product (Finke 1997). Examples include cubic meters of concrete or meters of pipe placed per labor hour. Some companies use the invers (e.g., X amount of labor hours per cubic meter of concrete placed). Other companies refer to a crew hour instead of a labor hour [American Association of Cost Engineers (AACE) 2004]. In any event, productivity is the same: some relative comparison between work output and work input.

Loss of productivity is experienced when a contractor does not reach the planned rate of productivity (i.e., the contractor is expending more effort per unit of production than originally planned). The result is a loss of money for the contractor and a delayed and possibly more costly project for the owner. Therefore, an important, sometimes challenging aspect of construction cost control is measuring and tracking work hours and production in sufficient detail to allow analysis of the data. Without this level of data, it will be impossible to determine the true root cause(s) of any poor labor productivity and to take early remedial action to forestall further deterioration or restore it.

Many papers have been written about change, but few document the prevalence, severity, and impact of change in a reliable, quantitative way. The purpose of this paper is therefore to present the findings from a research study of the combined data from two previous studies (Leonard 1988; Ibbs 2005). These two studies were reported previously for their individual sets of projects. Combining

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them gives one larger data set that enhances statistically reliability. This paper also presents the results of a series of statistical tests that were not previously performed, and addresses issues such as the probability of a project schedule overrun or cost overrun.

The result is a series of curves that project owners, contractors, and other parties can use to compare their projects against a large set of industry projects. Such reference points can help the parties manage projects in a prospective, proactive manner if they are contemplating a change. They can also help the parties retroactively assess the impact of change when looking for guidance to settle disputes.

Successful prosecution of a claim generally requires that three elements be demonstrated: liability, causation, and resultant injury (damages).[2] This paper addresses only the resultant injury issue.

Literature Review

Many articles have been written on the subject of change over the years, covering a wide range of aspects of change: causes, qualitative impacts, management processes, measurement techniques, and more. One aspect that is still not completely settled is the quantitative aspects of change: frequency, severity, and impacts on labor productivity.

One of the earliest quantitatively oriented articles is Merrow et al. (1981), who studied pioneer process plants and found that actual costs overran estimates by as much as 100% depending on the estimate class. They also found that pioneer projects had serious schedule problems and commonly required more than one extra year to reach design operating performance. Diekmann and Nelson (1985) examined the cost of change orders on 22 federal construction projects and found that change orders on these projects averaged 5.5% of the contract value. Hester et al. (1991) studied the frequency and magnitude of change orders for insulation work on one industrial project. Semple et al. (1994) found that 11 lump sum contracts had 44% cost increase and 74% time increase, and eight unit price contracts had an 88% cost increase and a 48% duration increase. Hinze et al. (1992) concluded that cost overruns tend to increase with project size. Lee (2007) compiled a comprehensive review of the many published articles that measure how a change in one discrete factor's (e.g., weather, overtime) impacts productivity. The Mechanical Contractors Association of America (2005) has published reports on discrete change factors and their impacts on productivity on the basis of member experiences. Anastasopoulos et al. (2010) analyzed the frequency of change orders for Indiana highway projects and developed statistical models to assess the influence of project type, contract type, project duration, and project cost on the frequency of change orders. Guerrant (1997) and Jones (2001, 2003), among others, looked at legal aspects of changes, especially cumulative impact changes.

Other prominent papers that deal with change and its impact on labor productivity are by Leonard (1998), Ibbs (1997, 2005), Thomas (1995), and Hanna et al. (1999a, b). Leonard's thesis is one of earliest and most widely cited publications on the subject of quantitative impact of change (Leonard 1988). In that study, Leonard collected data from 57 projects and organized the data into three project types: electrical/mechanical building work, electrical/mechanical industrial work, and civil/architectural work. (Ultimately, Leonard combined electrical/mechanical building and electrical/mechanical industrial work into just electrical/mechanical work because the two had no meaningful difference.) Leonard also organized the projects into those that had change orders only, change orders with one major cause of delay, and change orders with two or more major causes of delay. Projects were measured for percent change orders and productivity. Percent change orders were measured by the ratio of change order labor hours to actual contract labor hours, with actual contract hours being the project's total labor hours minus the change order labor hours minus any contractor mistakes. Loss of productivity was for the most part calculated using an earned value to actual productivity ratio. From that, Leonard conducted statistical analyses and developed statistical correlations between change orders and productivity.

This resulted in two different graphs, one for civil/architectural contracts and the other for electrical/mechanical work. Each graph had three linear curves, one representing projects substantially affected only by change orders and the other two curves representing projects substantially affected by change orders with 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; increased complexity of work; and a ripple effect of change orders issued to other contractors. Leonard believed the results were statistically reliable for change rates in the 10–60% range. Two key findings were that large amounts of change create large amounts of productivity loss, and change orders can cause productivity loss on both the change work and the base contract work.

This work has been the subject of considerable discussion and criticism (McEniry 2007). One common criticism is that the research included projects that had reached the dispute stage, which very likely resulted in loss of productivity curves that were skewed to the more disturbed end of the spectrum.

Ibbs (1997, 2005) has studied the subject. Data for 169 large, diverse projects have been collected and analyzed to date; the original data set included 104 projects studied during a Construction Industry Institute (CII) research investigation. As explained in previous publications (Ibbs and Allen 1995a, b), the CII member companies were asked to submit projects they believed were representative of their businesses. The data included project type, location, organizational structure, delivery system, and changes in cost, schedule, and labor hours. Change, labor hours expended, labor hours forecast, and other data were reported at the 0, 25, 50, 75, 80, 85, 90, 95, and 100% complete points in both the design and construction phases so that timing aspects could be studied.

Project size (on average $79 million total cost and 600,000 labor hours) was larger than Leonard's data, and projects came from 12 countries and included design phase information. Total installed costs for these projects ranged from $3.2 million to $15 billion, with most projects (64%) in the $20 million to $100 million range. Different delivery systems, different industry sectors, and grassroots and revamp projects were examined. Telephone and in-person follow-up interviews were conducted to verify that the projects were a representative sample. Since that initial research study, 65 more projects have been studied through initiatives at the University of California at Berkeley. Just like the first set of 104 projects, the subsequent 65 projects have been selected with attention given to whether they are representative of the construction industry.

Thomas and Napolitan (1995) reviewed 522 days' work on three different projects. This analysis showed that on many days (fewer than half) it was possible to incorporate change orders into the project without hurting labor productivity. However, the average impact for all changes was a 30% loss of productivity, indicating that when the impact is negative, it is substantial. The analysis concluded that the timing of change was a key variable affecting productivity. Ibbs (2005) has published curves that further substantiate that timing is crucial, sometimes doubling the consequences that change has on productivity.

The work of Hanna et al. (1999a, b) has concentrated on mechanical and electrical contractors acting in either a prime or subcontract capacity. Multiple regression models were developed to estimate the cumulative impact on labor productivity for mechanical and electrical construction resulting from changes. One model uses five input variables: original estimated labor hours, impact classification, total estimated change hours, number of change orders, and the timing of changes (Hanna et al. 1999a). Another model includes six significant factors: percent change, change order processing time, overmanning, percentage of time the project manager spent on the project, percentage of the changes initiated by the owner, and whether the contractor tracks productivity or not (Hanna et al. 1999b). It is not clear why these models would have different input variables.

As this paper indicates, considerable uncertainty still exists about the frequency and severity of change, from Diekmann's finding that project cost increases average 5% to Semple's 88%. What is missing and needed is a review that combines the data sources and narrows the range of possible variation. This paper presents such an analysis, with the intention of allowing the industry to better understand the magnitude and multidimensional nature of the problem.

Research Methodology and Analysis

To add to and improve the quantitative impacts of change research, this study combined and analyzed the Leonard and Ibbs data because they are similar data from two large sources. Together the Leonard-Ibbs database contained 226 projects, mostly large projects with information provided by the general contractor or owner. The Thomas and Hanna studies previously referenced were not included because the Thomas study focused on just a few projects, and the Hanna study examined electrical and mechanical projects that were much smaller because they were typically subcontracts.

The Leonard data were extracted from Leonard's thesis and entered into a spreadsheet. Because the data have been criticized as being unrepresentative of the industry's typical project, the data were statistically compared with the Ibbs data as a first step. Generally, project performance and change incidence for the Leonard data were slightly worse than for the Ibbs projects, buttressing the belief that the Leonard projects come from a set of disputed and, hence, more disrupted projects. However, the difference was so minor that the advantages outweighed the disadvantages, and the two sets of data were combined. Statistical curve-fitting and regression-testing procedures were then applied to the data. The results were reviewed and interpreted. The findings and their implications are discussed in the following sections.

Original cost, estimated labor hours, and original duration are defined in this study as the values in the contractor's original bid, corrected for contractor mistakes. Cost overrun (actual cost minus original estimated cost) is divided by the original estimate. Schedule overrun is defined analogously. The productivity index (PI) used in this paper is planned productivity divided by final actual productivity.

Findings

Eight figures are shown and discussed in the following subsections. The dots on these charts represent individual projects in the combined database. The dots are sometimes hard to read because they may be printed on top of each other, making it difficult to discern individual projects on these figures. The solid line in each figure is the best-fit regression equation. The equation in each figure is the best-fit regression function, and the R^2 value is the regression coefficient. $R^2 = 1.0$ would indicate perfect correlation between the equation (predicted value) and the actual data; $R^2 = 0.0$ would indicate no correlation.

Correlation indicates association, not causation. Therefore, the findings presented in this paper should not be used in a rote manner to forecast cost, schedule, and productivity impacts. The figures show an important visual component to the findings, and the accompanying text discusses the trends and implications of each finding. The regression equations and correlation coefficients give a fuller understanding of the data, including the reliability of the best-fit curves.

Project Cost, Productivity, and Schedule Characteristics

Fig. 1 shows the probability of different amounts of total project cost overrun. The horizontal axis compares a project's final cost with its budget, and the vertical axis shows the cumulative probability of a particular amount of cost underrun or overrun.

On average, the cost underrun was 3%, and the median amount of change was 9%. The cost variation was very large, with the best performing project underrunning budget by 43% and the worst overrunning the budget by almost 200%. Approximately 58% of the projects had no cost overrun. This does not mean that any project in the future will necessarily have a 42% (100% − 58%) chance of an overrun, it simply means that these projects did not. However, past performance on these projects is suggestive of performance on future projects. Of the projects in this combined data set, 20% had a cost overrun of more than 45%, whereas 10% had a cost overrun of at least 83%. Cost in this case is total cost, which would include the labor, material, construction equipment, subcontractor, and general condition components.

Fig. 2 shows the labor portion of these projects. It shows labor-hour variations for these projects, as exemplified by the PI (planned productivity divided by actual productivity). The first noticeable feature is that the PI ranges widely, 0.3–1.34. More than 50% of the projects had a PI in a 0.95–1.05 band, with an overall average of 0.97. Approximately 40% of these projects had PI < 0.8. This means that these projects incurred 20% or more loss of productivity, which is substantial and severely reduces the likelihood of project success. The humps in this curve at PI $= 0.4$ and 1.2 are mathematical anomalies.

Fig. 3 shows the probability of schedule overruns in the Leonard-Ibbs combined database. The average project overran the original schedule duration by 16%, as measured in calendar

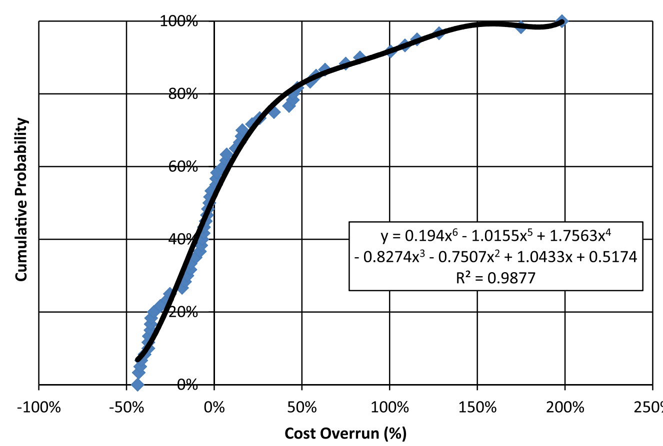

Fig. 1. Probability of cost overrun

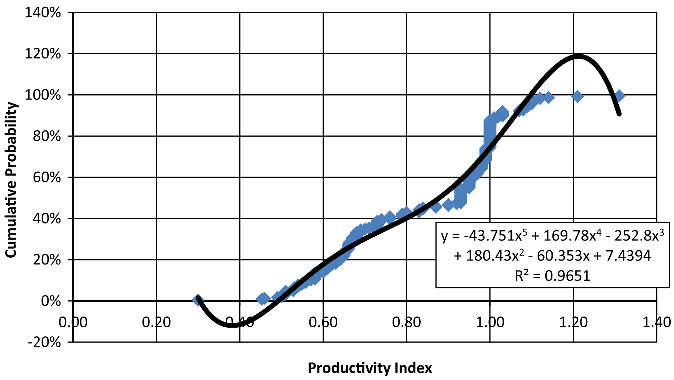

Fig. 2. Productivity index probability

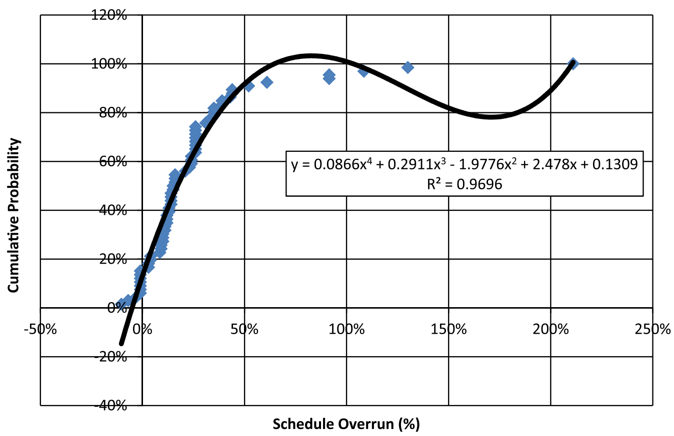

Fig. 3. Probability of schedule overrun

days, so more than half of all projects studied finished ahead of schedule or within 16% of original completion date. The statistical distribution of projects schedules was skewed by some projects that had extraordinarily large overruns. Approximately 7% of the projects had more than 50% schedule overrun, but 15% finished ahead of the plan.

More projects may have exceeded their completion dates if contractors had not taken mitigation measures. One of those mitigation measures involves adding more labor resources to a project, either in the form of more laborers or more work hours for the existing crews (i.e., overtime). The downside of adding more laborers or more work hours is the impact it has on labor productivity.

To explore this interaction between productivity and schedule performance, Fig. 4 was created. It compares the PI with schedule performance. This diagram shows the general relationship between PI and schedule performance in these projects; namely, a better PI is associated with better schedule performance. The correlation is low though. A negative schedule overrun value on the vertical axis means that the project finished ahead of time.

Close examination of this figure shows that project schedules never overran for a PI > 0.95. Projects that had PI > 1.0 usually finished ahead of schedule. These results are understandable because projects with good productivity generally run smoother. Schedules overran on average by 54% for PI < 0.95. Yet even for a PI < 0.8, some projects managed to finish on time, very likely indicating that schedule was given high priority even at the expense of productivity and cost. As productivity deteriorated, schedule variability increased. As an example, in the PI $= 0.65$ region, some projects had 0%

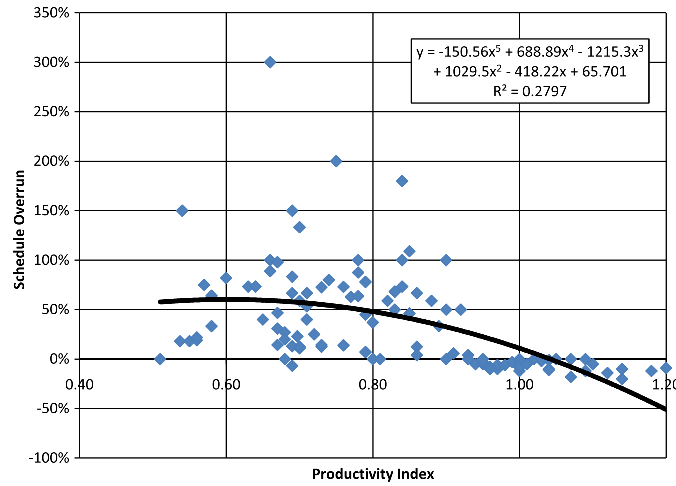

Fig. 4. Productivity index versus schedule overrun

schedule overrun, and some had 300% overrun. This indicates that when projects have a low PI value, both their average schedule performance and schedule reliability suffer substantially.

Fig. 5 shows the analogous relationship between productivity and cost overrun. Lower PI values are associated with more cost overruns. Two factors are probably at work. One is that the lower PI means that more labor hours are needed to complete the scope of work. The other, less direct factor is that a lower PI tends to lengthen the project schedule and, in turn, increase the general condition costs. The chart is notable for (1) the clustering around the (0, 0) origin, (2) how variable the cost overruns become once PI < 0.85, and (3) costs always overran by at least 20% once PI fell below 0.70. Costs, in this case, are total costs, which include material, general condition, construction equipment, subcontractor, and labor costs.

Likelihood and Severity of Change

The previous section reviewed the likelihood and severity of project cost and schedule overruns. In this section, the likelihood and severity of project change are discussed.

The average amount of change for these projects was 8% (Fig. 6). Change in this figure is measured by the amount of labor hours that have been formally recognized by the parties as being a contractual change and converted in change orders. The most

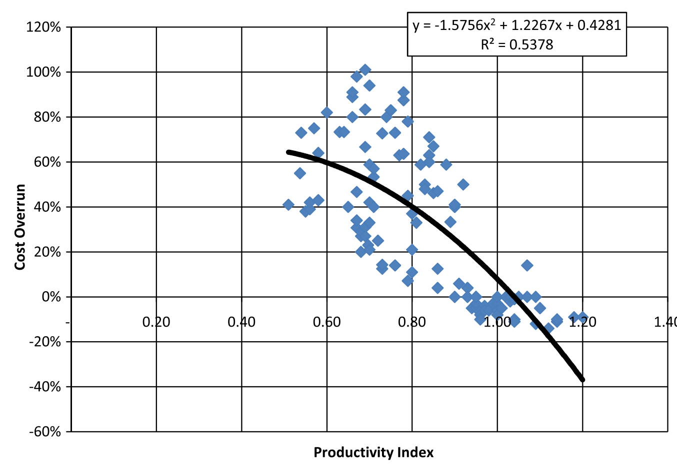

Fig. 5. Productivity index versus cost overrun

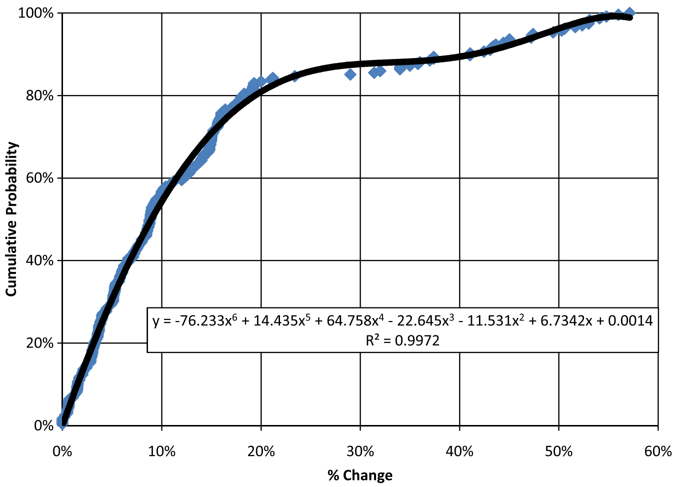

Fig. 6. Probability of various amounts of change on projects

change any one of these projects had was 58%. The difference between the Leonard and Ibbs projects was more striking in this regard than in other areas. Of the Ibbs projects, 11% had no change, whereas a smaller number of the Leonard projects (5%) had no change, very likely because the Leonard database was extracted from a set of disputed projects.

Of all projects, 59% had 10% or less change, and 16% had more than 30% change. This is noteworthy because it is industry convention that a cumulative impact condition may occur when change exceeds 10% (Leonard 1988). In such circumstances, it becomes difficult, if not impossible, to pinpoint a cause-and-effect relationship between a change event and its damage (Jones 2001).

Owner-caused change is not always converted into change orders. The contractor may decide to not pursue compensation, possibly because the amounts involved are negligible or because the contractor believes absorbing such losses will earn goodwill from the owner that will be useful later in this or some other project. Fig. 7 shows this in quantitative terms. Namely, it shows the proportion of labor hours that were actually converted into change orders divided by the number of labor hours that could have been converted into change orders. This figure was developed by dividing the number of labor hours in awarded change orders by the number of labor hours that could have legitimately qualified as change orders. As an example, approximately 80% of the time (the vertical axis), 78% or more of a project's changes became

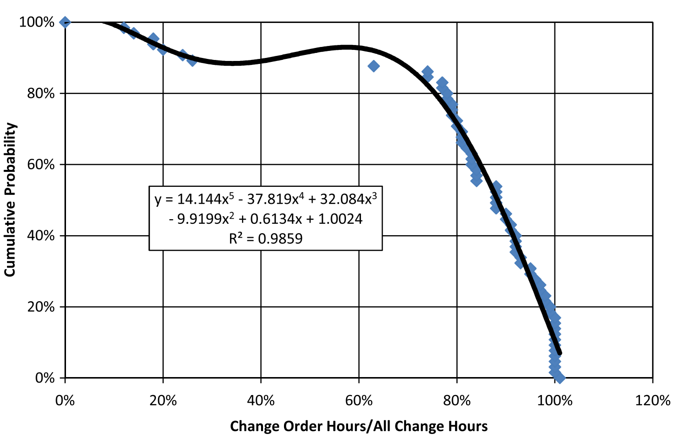

Fig. 7. Percentage of project change that became change orders

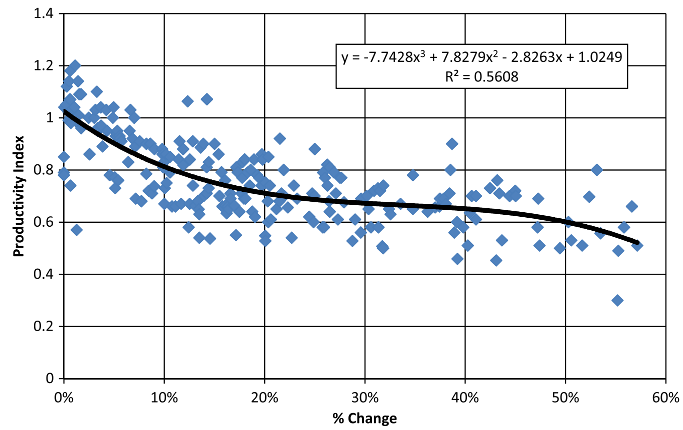

Fig. 8. Percentage change versus loss of productivity

change orders. This belies any assertion that a large portion of changes that contractors file are spurious. The balance of changes that are not converted into change orders would be absorbed by the contractor or subcontractors.

Change's Impact on Labor Productivity

Analysis of the combined data sets reveals that a correlation exists between a project's PI and the amount of change it incurs. Fig. 8 shows that projects with more change generally have a lower PI. As an example, projects with 20% change have an average PI of 0.82, meaning an 18% loss of productivity. This figure also shows that a high degree of PI variability is present in this particular aspect of the data. Projects that had low amounts of change tend to have tightly bunched PI rates, whereas projects with larger amounts tended to have more variable rates. For instance, at 10% change, the PI ranged from 0.67–0.88 (a 0.19 range), whereas at 20%, it ranged from 0.55–0.85 (a 0.30 range). This means that both productivity and the predictability of productivity deteriorate with increasing amounts of change.

It is also noteworthy that actual productivity never reached planned productivity once change exceeded 15%. When change was fewer than 5%, PI exceeded plan 60% of the time. Minimizing change is thus important for realizing good productivity performance.

Discussion and Recommendations

Numerous general implications flow from these findings. First, project cost uncertainty is larger than commonly thought. Fig. 1 shows this, with costs ranging between an underrun of almost 50% and an overrun of 200%. Various industry guides propound ranges of estimate accuracy for certain categories of estimates. As one example, the U.S. Army Corps of Engineers (2000) indicates that 67% (1 SD) of all final design estimates should fall somewhere between 10% under estimate and 15% over budget.

Fig. 1 shows that a better range would be $-30\%/+50\%$. This comes from identifying the x-axis values for $y = 0.17$ and $y = 0.84$ (a range of 67%, 1 SD), the lower bound and upper bound for a normally distributed population of projects. One consequence of such an enlarged range would be that projects should have more contingency amounts attached to them before construction begins. This, in turn, may mean fewer projects may be authorized initially unless a company's (or agency's) budget is adjusted accordingly. However, a more accurate projection of project budgetary risks would allow better management of capital programs, specifically fewer surprises as projects near completion.

A second major set of findings that is noteworthy concerns the schedules of these projects. All projects finished ahead or on schedule for a PI > 0.95 (Fig. 4). Most projects experienced a schedule overrun of 0–100%, whereas cost performance was more variable (ranging between −50% and +200%), meaning schedule performance was more predictable. Schedule performance became very unpredictable for PI < 0.95, whereas it was very stable and predictable at PI > 0.95. Some low PI projects had on-time schedule performance, probably because schedule was given overriding emphasis at the expense of productivity and costs. Such emphasis undoubtedly further contributed to lowering the PI. If the PI is good, schedule performance is likely to be favorable.

Another finding of this study is that productivity was very variable in these projects, as shown by the R^2 factor in Fig. 8. The projects that suffered a 40% change rate saw PI as low as 0.44 and as high as 0.96, more than double. It is difficult to manage projects when productivity is so unpredictable. On the other hand, this figure also shows that the chance is very good that actual productivity would exceed planned productivity if change was held to fewer than 5%.

Some authors have written that cumulative impact may occur when change exceeds 10% and is a rare condition (Leonard 1988; Long 2005). However, in this study, 41% of the projects had 10% or more change (Fig. 6), meaning that it is not a rare phenomenon. For the combined set of projects, a 10% change rate corresponds to an 18% loss of productivity (Fig. 7). Even at 7% change, an almost 15% loss of productivity exists. Cumulative impact may therefore occur at lower rates of change than the commonly accepted 10% level. In such circumstances it becomes difficult, if not impossible, to pinpoint a cause-and-effect relationship between a change event and its damage (Jones 2001). This is a significant loss of productivity and reduces the likelihood of successfully completing the project, either on budget or on time. More research is needed.

When viewed together and from a broader point of view, these data, curves, and findings have variation. However, that variation is not surprising for numerous reasons. As AACE (2004) notes, the variations may be owing to the many different types of projects and the fact that the projects were built in many different geographical locations, using many different means and methods. A transient and diverse workforce with different skills and training levels may contribute to these variations. The variation may also be owing to poor record keeping by contractors. However, even in situations in which good record-keeping protocols exist, some change may not be easily detected or observed at the outset. Such change must be recognized and tracked by field and project controls staff. It must be tracked promptly and contemporaneously for the contractor to even have a chance to measure all the impacts of to be captured.

Even with such variations, the curves are useful guideposts for both proactively and retroactively estimating a change's impact on projects, even in the eyes of such strict tribunals as courts. Writing about a specific type of construction change dispute, Shea (1989) said

> One of the ironic things about loss of productivity claims is that often the very factors that produce the loss of productivity can also serve to preclude the accurate and precise record-keeping that would constitute evidentiary certitude. The disruptions, impacts, need for acceleration, lack of information or decisions by the [owner] make it more difficult to track the specific causes and effects of the situation.

Accordingly, the courts have adopted a flexible attitude toward the evidentiary requirements and proof needed to establish damages.[3]

In other words, the degree of variation in the findings presented in this paper may be large (and perhaps even larger than commonly thought), but that does not necessarily preclude analysis and resolution of disputes.

Conclusions and Recommendations

Even when a project has little or no change, costs, schedules, and labor productivity can vary significantly from plan. Projects that have change, even small amounts, are much more likely to have worse cost and schedule performance than budgeted. This paper quantitatively examined 226 projects collected by Leonard (1988) and Ibbs (2005) in an attempt to better quantify patterns.

The findings of this study clearly indicate that minimizing change is important for realizing good cost, schedule, and productivity performance. Change is sometimes necessary, but as this study shows, change almost invariably affects the project, and often the full impact of change is not fully recognized when the change is first authorized. Change should therefore be authorized cautiously and conservatively. It should also be tracked as carefully as possible, recognizing that all the impacts of a change may not be foreseeable at the time the change is recognized and executed.

General industry studies normally should not replace project-specific analyses. However, they may actually be the only option in projects in which the contractor did not or could not keep proper records. The studies referenced in this paper and curves presented can also be used to corroborate use of project-specific reviews, including measured mile and modified total cost approaches. The curves in this paper require careful application and should be used judiciously, with full understanding of the circumstances under which they were developed.

List of Cases

Centex Bateson Construction Co., VABCA No. 4,613, 99-1 BCA ¶30,153, at 149,259 (1998).

Elete, Inc. v. S.S. Mullen, Inc. 469 F.2d 1,127 (1972).

E.C. Ernst, Inc. v. Koppers Company, Inc., U.S. Court of Appeals, 626 F.2d 324, 327 (3d Cir. 1980), 476 F. Supp. 729 (W.D. Pa. 1979).

S Leo Harmonay, Inc. v. Binks Mfg. Co., 597 F. Supp. 1,014 (S.D.N.Y. 1984).

Endnotes

[1]Cumulative impact was defined in *Centex Bateson Construction Co.* as "the unforeseeable disruption of productivity resulting from the 'synergistic' effect of an undifferentiated group of changes."

[2]Liability is a legal right to recover pursuant to the contract or owing to the breach of the contract by a defendant (often an owner) and evidence of defendant-caused disruptions (Jones 2003). Causation is a persuasive explanation of what triggered the change and an explanation of how the alleged effects are related to that trigger. A plaintiff (frequently a contractor) needs to present a reasonable estimate of the loss of productivity caused by changes to satisfy the last requirement. Although the liability can be straightforward, causation and resultant injury may be more difficult to prove.

[3]The court in *Elete, Inc. v. S.S. Mullen, Inc.* wrote, "The difficulty of ascertainment of damage is not to be confused with the right of recovery. The rule is that, if the plaintiff has produced the best evidence available and if it is sufficient to afford a reasonable basis for estimating his loss,

he is not to be denied a substantial recovery because the amount of damage is incapable of exact ascertainment." In *S Leo Harmonay, Inc. v. Binks Mfg. Co.*, the contractor's difficulties in tracking productivity with the precision found in other engineering situations were recognized and excused: "It is fundamental to the law of damages that one complaining of an injury has the burden of proving the extent of the harm suffered; delay damages are no exception…On the other hand, courts have often recognized that the extent of harm suffered as a result of delay, such as the loss of efficiency claim in issue, may be difficult to prove. Thus, courts have recognized that the plaintiff may recover even where it is apparent that the quantum of damage is unavoidably uncertain, beset by complexity, or difficult to ascertain. As the New York Court of Appeals commented: 'The law is realistic enough to bend to necessity in such cases.'" Finally, in *E.C. Ernst, Inc. v. Koppers Company, Inc.*, "damages need not be proven with mathematical certainty…evidence of damages may consist of probabilities and inferences."

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