

THE IMPACT OF CHANGE'S TIMING ON LABOR PRODUCTIVITY**WILLIAM IBBS¹, M.ASCE****PAPER No. CO/2003/022889**

ABSTRACT: There are many types of construction change and each type can have an effect on labor productivity. To a certain extent though the specific type of change is not as important as the mere presence of the change and, as analyzed in this paper, the timing of that change. The research reported in this paper reaffirms that project change is disruptive and detrimental to labor productivity. Data from 162 construction projects were statistically analyzed and a series of three curves are presented in this paper, representing the impact that change has on the labor productivity for early, normal, and late timing situations. The projects are a representative sample of the industry, involving a wide range of sizes, different delivery systems, and industry sectors. Late change is more disruptive of project productivity than early change, all other things being equal. The implications and benefits of this research are clear: if changes are necessary, they should be recognized and incorporated as early as possible. Practitioners can use these data and curves for either forward pricing or retrospective pricing of changes. Other researchers can use these findings to test their own findings and to explore timing issues in further detail.

SUBJECT HEADINGS: Change, Construction, Construction Costs, Construction Management, Disputes, Labor, Productivity, Schedule Analysis.

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INTRODUCTION

Change, especially when it results in protracted disputes and litigation, is a serious and expensive problem for the Construction Industry. Diekmann and Nelson (1985) found that changes were pervasive and added about 6% to the direct cost of 22 government projects. A study of Veterans Administration, Corps of Engineers and Naval Facilities Command (NAVFAC) projects showed comparable experiences: cost increases in the 5.8% to 11.6% range. (NRC 1986) Semple, Hartman, and Jergeas (1974) analyzed 24 Canadian projects and found that averages can be deceiving: 50% of the projects in this data set had cost claims for more than 30% of the original bid value. These projects also had large claims for time extensions, in some cases 80% of the original contract duration.

Though the estimate is almost ten years old now, one industry group estimated that more than \$60 billion dollars is spent annually on changes in the U.S. (DART 95). In the latest US Corporate census, the value of construction work put in place in 1997 was \$1.3 trillion. (US Census Bureau 2003). A 6% change rate on this \$1.3 trillion would suggest that just the direct costs of change approach \$78 billion per year. In addition there are indirect costs such as higher insurance rates; delayed commissioning of projects; lost opportunity profits from projects that cannot be pursued; the costs of bidding and managing projects "defensively"; and so forth. There are also intangible costs; for instance, the personal cost to the careers of people who are enmeshed in acrimonious disputes. Of course there are instances where change can actually be a positive thing, and reduce a project's cost or improve its overall lifecycle value. But the wrong type of change can increase the cost of projects and reduce the economic value of a project

Change affects projects many ways, most importantly by disrupting and impairing a project's labor productivity. Different types of change have been studied by previous researchers: overtime, weather, schedule acceleration, etc. One aspect of change that has not been well

researched is the issue of change's timing. Ibbs et al (1994a) postulated that a change implemented late in a project will have more unsettling impact on labor productivity than the same change implemented earlier in the project. Aside from a case study in Ibbs et al (1994b), no rigorous analysis of timing effects has been reported. This paper presents such an analysis.

PROMINENT PREVIOUS RESEARCH

A considerable amount of research exists about the subject of construction change and how it affects craft labor productivity. For our purposes here, change is defined as any variation to the original project scope. It can be physical (more units of work) or less tangible (change the reporting requirements or re-sequence the project schedule to accommodate an earlier opening). Change can be responsibility of the owner, the contractor, the designer or a third party. And, it can be additive or deductive.

In this summary, we divide the existing research literature into two categories: discrete impacts vs. cumulative impacts. For brevity, we review only some of the more prominent studies.

More literature exists on the subject of discrete change's impact than on the subject of cumulative impact. Some of those studies are based on scientific research methodologies where empirical data are collected and analyzed, and other variables are controlled. As an example, the well-known Business Roundtable (1974) report on overtime portrays the effects that extended periods of overtime (50- and 60-hour work weeks for 1 to 14 weeks) have on labor productivity. In reality this study is an extrapolation of a series of small, independent projects over a 10-year time period. Thus, from a researcher's perspective, the experimental design behind these data is quite imperfect.

Grimm and Wagner (1974) and Koehn and Brown (1985) have studied the effects of weather, especially temperature and humidity, on productivity. Thomas (2000) examined the effects of schedule acceleration on productivity. Ibbs et al (2003) examined the amount of change for different project delivery systems. None of these studies examined the impact of change's timing on productivity, which is the subject of this research, though.

Other studies have been developed by less rigorous methodologies, or at least methodologies that are not explained. The Mechanical Contractors Association of American (MCAA) has published a guide that discretizes sixteen factors (e.g. stacking of trades, dilution of supervision) and the projected effect they have on labor productivity (MCA 1986). For instance, minor weather problems are listed as having a 10% impact, while severe instances can affect productivity by 30%. The source of this information is not explained. Likewise, proper application is not explained: What is the definition of "severe"? Are the reduction factors applied to the entire project or just the window of work that is affected by the changed condition? How should instances be analyzed where more than one of these sixteen factors is present so that redundancy and double-counting are avoided? The National Electrical Contractors Association, NECA, has a similar manual with twenty-five variables and five degrees of severity (NECA 1976). Examples of the types of variables listed in these two manuals are site layout, local weather conditions, and the worker's experience level. Amount of change and timing of change are not considered.

The Corps of Engineers Modification Impact Evaluation Guide is similar to the MCA and NECA manuals in that it contains productivity adjustment factors for a number of project variables; e.g. disruption, overcrowding, acceleration, and morale. (US Army Corps of Engineers 1979). The source of this information is not revealed, suggesting that it is anecdotal and judgmental. It was rescinded in 1996 without full explanation. (Geneni 1996).

Systematically, these three manuals suffer from another common problem. Namely, a question of objectivity exists because they were developed solely by parties with a vested interest and without the tempering perspective of the other project party. The MCA and NECA manuals were developed by contractor groups and the Corps manual was developed by an owner.

Cumulative impact is even more difficult to measure. For our purposes here, cumulative impact is the impact on productivity accruing from an aggregation of many changes. Even though the contractor may be able to forward price each individual change in a way that is literally accurate for the change per se, the accumulation and timing of such changes is so profound that productivity may be affected by the changes themselves. As recently expressed by the Veterans Affairs Contract

Board of Appeals, "Cumulative impact is the unforeseeable disruption of productivity resulting from the 'synergistic effect of an undifferentiated number of changes.'" (Coates Industries 1999).

Because causation is so difficult to pinpoint, there is considerable controversy over whether cumulative impact changes even exist (Jones 2001 and Jones 2003). Finke (1997) takes the extreme position asserting that "...there is no such thing as synergistic, greater-than-sum-of-the-parts disruption...." Instead, he argues that cumulative impacts are only local impact claims that the contractor failed to include when pricing the underlying, discrete change. These changes also are often very large, adding to their contentiousness.

Nevertheless Appeal Boards and courts have gradually begun to accept the premise of cumulative impact change if a strong and persuasive effort is made to demonstrate (not necessarily, prove) causation. This is consistent with the findings of Hester (1991) who led a team of researchers specifically dedicated to track change work. Despite their contemporaneous data collection and on-the-spot observation, these Berkeley researchers demonstrated that they could not precisely track all the interconnected work activities affected by a change.

The first study to analyze this problem rigorously was Leonard's. (Leonard 1988; and Moselhi et al 1991) It was his conjecture that changes by themselves create disruptions in the natural pace and momentum of a project. Even if the contractor is compensated for change work, the effects on remaining base contract work are subtle and real. To test his theory, he studied 90 claims on 57 different projects. He divided these projects into three categories: 1) those in which change orders were the only major cause of productivity impact; 2) those in which there was one other major productivity inhibiting factor; and 3) those where two other such factors were prominent. The inhibiting factors for which he tested were inadequate coordination and scheduling; acceleration; impeded access; and changing priorities. He then developed curves that show the amount of productivity loss for different levels of change.

As valuable and pathbreaking as this study was, it has some methodological problems. One is that the severities of the productivity inhabiting factors were qualitatively assessed. Also, the studied projects were culled from a claims consulting company, suggesting that the disputes were

more contentious than normal. And some have argued that the weather, labor conditions, building code requirements, etc. of the Canadian marketplace are significantly different from the American Industry.

Subsequent to Leonard, Ibbs and Allen (1995) analyzed a set of 104 projects. That study represented a cross section of the construction projects, consisting of 1) both disputed and undisputed projects; 2) design as well as construction phase performance information; 3) industrial, commercial, heavy/civil projects; 4) foreign vs. domestic; and 5) various delivery systems. (Ibbs 1997) This was therefore a study of more projects and a more diverse set of projects than the Leonard study. Change was found to have a significantly significant effect on both design and construction productivity. Actual construction productivity exceeded planned productivity when the project experienced less than 6% change. Actual design phase productivity never exceeded planned productivity, regardless of the amount of change.

Thomas and Napolitan (1995) studied productivity at the crew level, which required introducing a "work conversion" step. Analogous to an earned value calculation, they adjusted their productivity factors for the specific type of work that the crews were performing; e.g. large bore vs. small bore pipe. Their analysis showed a 25-50% efficiency loss, depending on the specifics of the change. Their study's applicability is limited by its small sample size (three projects representing 522 workdays). Also, by focusing only on the individual crew being directly studied, they ignored potential ripple effects a change may have to adjacent crews and work.

Ibbs et al (1998) analyzed the effects of fast-tracking design-build projects by testing the hypothesis that projects with more aggressive fast-tracking (i.e. construction started earlier in the design phase) had more change than projects with less fast-tracking. Somewhat surprisingly, the amount of change was found to not be significantly different between the two groups of projects. One possible explanation might be that project managers prepare and plan more thoroughly because they think change may be more problematic on the aggressively fast-tracked projects.

Subsequent studies were conducted by Hanna (1999a, 1999b), using data from thirteen mechanical contractors on 61 projects and 26 mechanical contractors also on 61 projects. (It is not

clear if these were the same 61 projects.) The average size of the mechanical contracts was \$1.9 million. No dollar amount was reported for the electrical jobs but they too appear to be small. All contracts were fixed price/lump sum. The studies find, among other things, that labor productivity differs for projects that are impacted by change. As with other studies, the impact of change's timing is not discussed and appears to not have been considered.

Regression models were developed for each of the two types of work. The electrical model had only four significant independent variables, while the mechanical model was found to have ten key variables. The only variable common to both models was an "impact classification" variable. No explanation was given why the models had different significant variables.

There are several limitations with this study, one being the use of the "impact classification" variable. This variable was qualitatively assessed by the contractors responding to the survey. Those contractors, who have a vested interest in the results of the study, ranked the degree to which their projects were affected by factors such as change orders, work sequence disruption, trade stacking, material problems, weather conditions, overtime, and shift work. Not all of these variables are the responsibility of the owner, though the model presumes such. Weather risks – as an example – may be contractually allocated to the contractor. Moreover, the ranking was done on a subjective 0 to 5 scale, "less" to "more". The authors do not explain how they controlled for this subjectivity.

Another unclear aspect is that the number of change orders is a significant variable in the mechanical. Thus the same job could have two different predicted productivity losses, depending only on whether an owner approves a particular change order request, not on the merits per se of the change.

Two key assumptions with all these studies are that 1) the contractor's estimates of the original work and the change order work are accurate; and 2) the contractor did not mismanage his part of the work. These are major assumptions and could easily and substantially skew the results if they were not accurate representations of the project conditions. Short of more painstaking and expensive analysis of each individual project in this dataset, there is no way to confirm or refute

them. Despite such limitations, significant progress has been achieved in understanding and modeling labor productivity since Leonard's study of fifteen years ago.

RESEARCH METHODOLOGY

The data reported in this study have been collected over the past nine years, beginning with the original Ibbs and Allen CII study (1995). A total of 162 disputed and non-disputed projects have now been benchmarked from 93 contractor, CM, design and owner organizations. Other salient facts are:

- 45% are public sector projects and 55% private sector.
- 63% are Design/Bid/Build, 27% Design/Build, and 10% a hybrid or conversion.
- Project size ranges between \$3.9 million and \$14.5 billion.
- 35% of the projects are heavy/highway; 16% are commercial; and 49% industrial.
- The data is for labor productivity experienced by both a project's prime contractor and, when available, the subcontractors.

Cost, labor-hour, schedule and change data were collected at the 25%, 50%, 75%, 80%, 85%, 90%, 95% and 100% milestones of both design phase and construction phases, whenever possible. The data were analyzed using conventional regression analysis.

Productivity in this paper is actually a performance ratio: actual productivity divided by planned productivity. Values above 1.00 indicate performance better than expected. This analysis is based on end of project productivity values. A key assumption in this analysis is that the planned productivity level was accurate; if it was not accurate then this ratio of actual-to-planned productivity would misstate the amount of productivity lost.

RESEARCH RESULTS AND DISCUSSION

Figure 1 summarizes the rate of accumulated change over the projects in this database. The project's construction schedule is portrayed along the horizontal axis and the vertical axis represents the amount of change incurred in the project from the outset of construction. Change is

measured in absolute terms, meaning that a project that \$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 changes would understate that disruption. For example, netting the difference between \$1 of additive and \$1 of deductive change would indicate that there was no change even though there were probably productivity perturbations.

The projects are rank ordered according to the time when a change was formally recognized. Formal recognition in this case is when one party notifies the other by either verbal or written notice, whichever is earlier. There is some imprecision in this definition but this researcher felt it was the best choice available.

The middle line in Figure 1 shows the mean rate of change incurred for these jobs. Roughly 58% of the change was occurred by the time the project was 50% complete. The outer two lines represent confidence limits for the projects with the fastest and slowest rates of incurred change. Almost 40% of all change was recognized by the 10% point in the fast projects, while 40% was reached until the 60% point in the slow projects.

Figure 2 shows that rate at which construction labor productivity decreases with increasing amounts of project change. Projects with no change had actual labor productivity about 6% above planned. Projects with 3% change had labor productivity = 1.00, meaning the actual rate equaled the planned rate. The line slopes downward and asymptotic to 0.60, representing a 40% productivity loss. The polynomial equation listed in the figure represents the best fit. Linear and exponential forms were also tried. The correlation coefficient ($R^2 = 0.72$) is displayed in the figure, indicating a relatively high goodness of fit in this case. The data reveal that productivity is more predictable at low amounts of change than at higher rates of change. For example, the standard deviation for the productivity of projects with 0% to 10% change is 0.09 whereas for projects with 40% to 50% change, it is 0.15.

Next, projects are rank ordered into three groups: Early (the 25% of the projects were change was recognized fastest), Normal (middle 50%) and Late (slowest 25%) Change. Figure 3

conveys the results. Early and Normal projects have shallower curves and actually can tolerate a small amount of change before the productivity ratio drops below 1.00. The vertical distance between these two curves is relatively small.

Late changes, on the other hand, always result in a productivity ratio < 1.00 (substandard) and the rate of change (the slope of the late change curve) is more pronounced than is the case for either of the other two curves. In rough terms, late change is about twice as detrimental to productivity as normal or early change; e.g. at 10% change, the late change curve has a 20% productivity loss while the normal change curve indicates a 10% loss.

Productivity values analyzed here are cumulative, end-of-project values. So a late change has fewer labor-hours to impact when it occurs late in the project. Late change must therefore be extremely disruptive to the work-hours remaining in the late stages of the project because that disruption is powerful enough to drag the cumulative productivity value down below the other two curves, shown in Figure 3. That can be represented mathematically as

End-of-project Productivity = Eq. 1

$$\frac{(\text{PROD}_{\text{Unimpacted}})(\text{W-HR}_{\text{Unimpacted}}) + (\text{PROD}_{\text{Impacted}})(\text{W-HR}_{\text{Impacted}})}{\text{W-HR}_{\text{Unimpacted}} + \text{W-HR}_{\text{Impacted}}}$$

Conversely, it is easier to recover from early change because there is time to make up for lost productivity. Because this paper's focus is on timing aspects of change, no analysis of other project variables (delivery system, public vs. private) is reported here. It does appear, based on some ongoing studies, that these variables do not have a statistically significant impact on the presence of or severity of change.

RESEARCH RELEVANCE AND CONCLUSIONS

Change may occur late for various reasons. One explanation is that some discrepancies, omissions and needed work alterations are not discovered until the project is relatively far along.

This is particularly true in the detailed, finish trades, which tend to come in the later stages of a project. People, particularly project owners who are not accustomed to the construction process and construction drawings, may not fully envision the shape, flow and configuration of a project until it is nearing finished physical reality.

Another reason for late changes is that the project parties may be hopeful that they can amicably solve disagreements. Eventually such disagreements may have to be escalated to a higher organizational or more formal level of review, by which time the cost and time impacts have festered and become a more serious issue. One final reason for late change may be that owners may want to add more scope and features to the project if they have the funds available as the project concludes. Unspent contingency moneys may be a source of such "scope additions".

The research reported in this paper (and other studies) reaffirms that project change is disruptive to labor productivity. There are many types of change and each type has a unique effect on productivity. To a certain extent though the specific type of change is not as important as the mere presence of change and, as analyzed in this paper, the timing of that change.

The implications are clear: all other things being equal, early change should be encouraged and late change discouraged. Numerous contract management techniques exist for encouraging early and discouraging late change. One such instrument is requiring that proposed changes pass a financial hurdle rate (e.g. a benefit/cost ratio) before being accepted. By requiring the lower hurdle rates at the outset of a project, early change is encouraged.

APPENDIX I. NOTATION

DART	=	Dispute Avoidance Research Taskforce
MCAA	=	Mechanical Contractors Association of America
NAVFAC	=	Naval Facilities Command
NECA	=	National Electrical Contractors Association
PROD _{Unimpacted}	=	Productivity for an unimpacted project period.
PROD _{Impacted}	=	Productivity for an impacted project period.
W-HR _{Unimpacted}	=	Number of Work-Hours for an unimpacted project period.
W-HR _{Impacted}	=	Number of Work-Hours in an impacted project period.

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Captions for Figures

Figure 1: Timing of Project Change

Figure 2: Construction Productivity vs. Project Change

Figure 3: Construction Productivity vs. Timing of Change

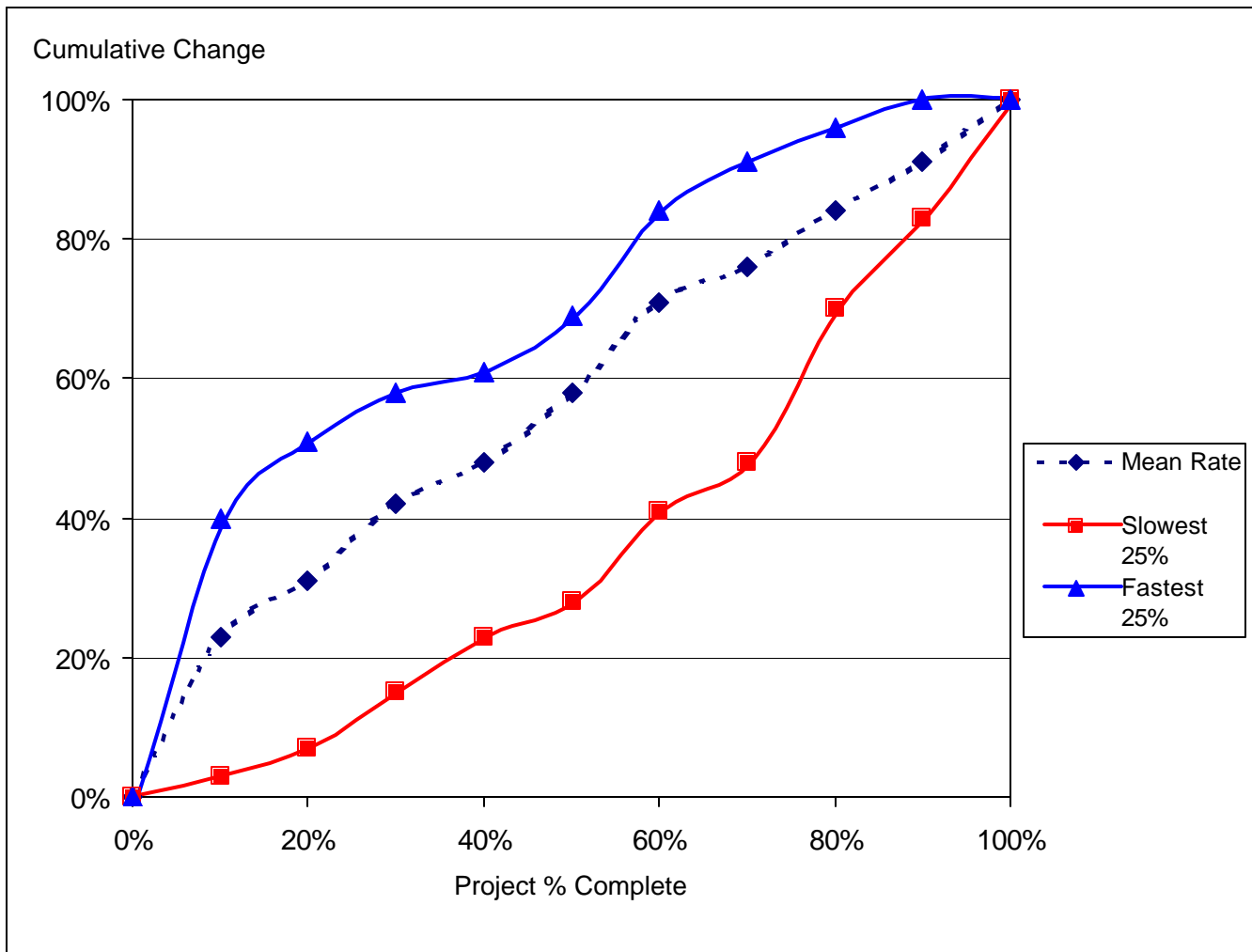


Figure 1
Rate of Change vs. Project Schedule

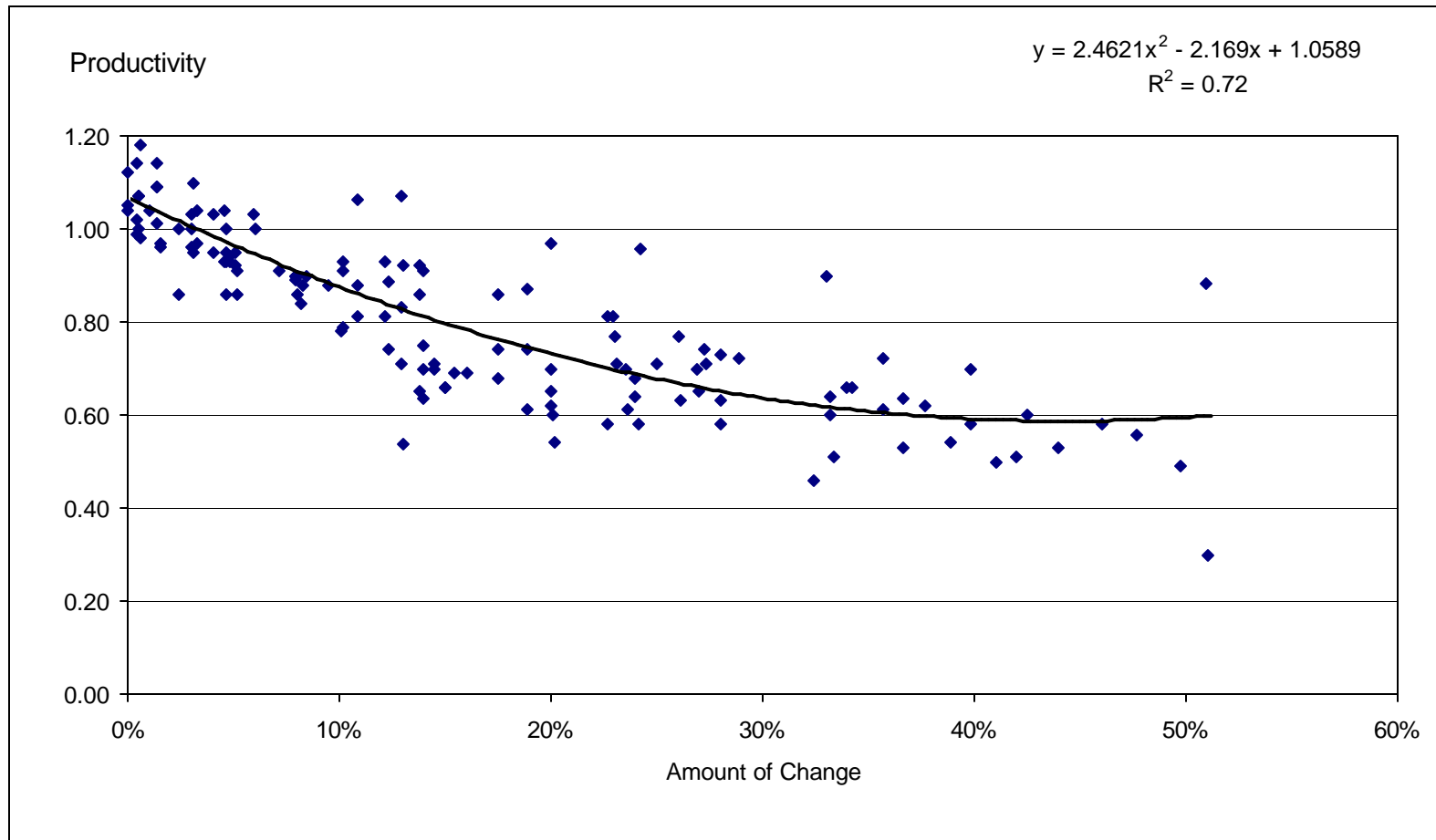


Figure 2
Construction Productivity vs. Project Change

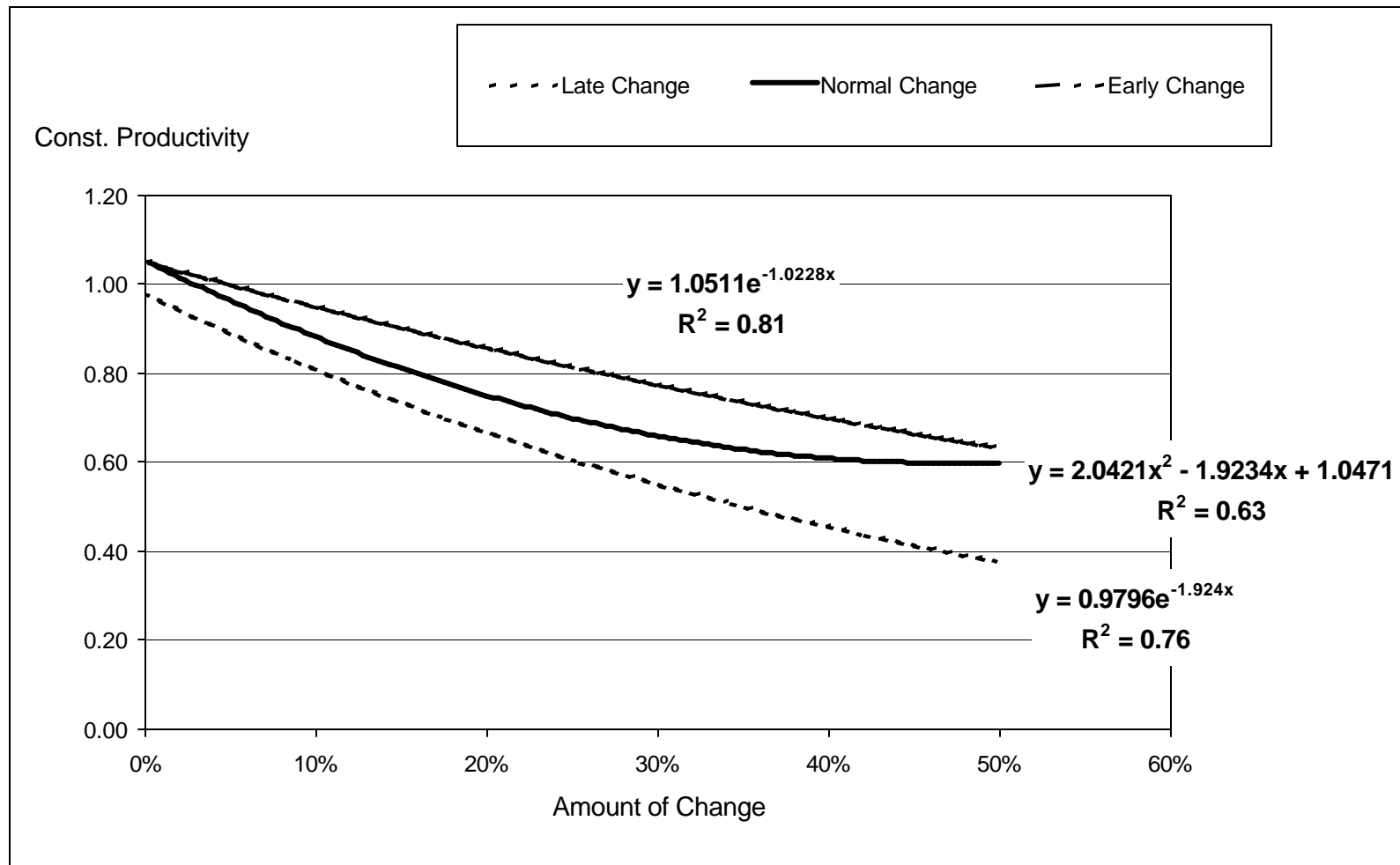


Figure 3

Construction Productivity vs. Timing of Change