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QUANTIFYING THE CUMULATIVE IMPACT OF CHANGE ORDERS FOR SHEET METAL CONTRACTORS

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QUANTIFYING THE CUMULATIVE IMPACT OF CHANGE ORDERS FOR SHEET METAL CONTRACTORS

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EXECUTIVE SUMMARY

Change on construction projects is inevitable and often the effects of change are disputed amongst owners and contractors. Change orders, the contractual method of issuing a change to a construction contract, are legal and present on every job. The complete effects that change orders have on a project are noticed by the contractor but are difficult to quantify. This difficulty lies in the fact that the total and complete costs of a change are not only the direct costs of the extra material and equipment hours that are needed to carry out the change but also the effect that the change has on the flow of work (its effect on labor) and the "ripple effect" that change orders cause through the project. This ripple effect has been defined as the cumulative impact of change orders and its sources impact on both the changed and unchanged work. Some sources of change order cumulative impact are dilution of supervision, out of sequence work, rework, schedule acceleration, etc.

Each of the above examples of cumulative impact will have an effect on labor and its productivity. It is this productivity loss that is difficult to quantify and prove. Contractors often seek legal claims for their loss but fail to convince the court because of the lack of hard data. The lack of a method by which to prove a loss of productivity as a result of change orders has spawned several researches, most notably the Leonard Study (1991) and the CII-Hanna Study (2000). The past research on the impact of change orders has primarily focused on general construction and the labor-intensive trades of electrical and mechanical construction. The current research focuses on the impact of change orders on labor productivity for a different and unique section of the construction industry: sheet metal.

The New Horizons Foundation undertook the issue of cumulative impact by forming a research team to investigate and develop a model that can estimate the productivity loss on a project impacted by change orders. The research resulted in the formulation of a regression model that can be applied to projects to generate a percentage loss of productivity due to changes. The components of the model include percent change, the type of work, project extensions, the coordination of the drawings, and the amount of owner furnished equipment. In addition to the regression model for determining lost productivity, the research also created project control tools and industry benchmarks that sheet metal contractors can use to minimize the impact of changes and help improve any project's productivity. A summary of the research follows, including recommendations for contractors, owners, and architects/engineers based on statistical findings that will increase the likelihood of project success.

On every construction project, contractors, owners, and architects expect to manage a certain number of change orders, modifications, or interruptions. The contract parties also expect that the costs of the changes or disruptions will be addressed by the contract language in the form of the Change clause (which allows the owner to make changes to the contract within limits) or some other remedy granting provision in the project documents.9 When small levels of change occur, contractors are generally able to accommodate the changes without noticeably disrupting the planned flow of the original scope of work. Additionally, owners justly presume the contractor will be able to accurately estimate the direct and indirect costs associated with the changes.

When, however, a project experiences numerous changes, the costs to the contractor to perform the work can increase due to the disruption caused by the changes to the planned work flow. As a consequence of the numerous change orders (or the timing of the changes), the contractor can experience a productivity loss and simultaneously be unable to accurately price the cost of the lost efficiency at the time of each individual change order. In essence, a project with numerous change orders can experience a "cumulative impact" due to the changes' ripple effect through the project work flow. This causes the contractor to experience financial distress that is often unrealized until the end of project billings.

Throughout the construction industry, the cumulative impact of change orders has caused the loss of productivity (and the loss of profits) on many projects and the need has arisen to develop models that allow contract parties to estimate the real cost of changes. This need has arisen from several conditions which have been changing gradually in the construction industry:^{2,14}

1. Decreased quality of design drawings -It is uncommon for a contractor to have a set of contract documents that has been fully and properly coordinated with all other aspects of the construction project. As a result, there is often a need for immediate changes on a project to resolve conflicts and interferences that should have been eliminated in the design phase. Also, many contract documents are vague and ambiguous in their intent and contain errors or omissions that add to the cost of work.¹⁴ Additionally, one need only ask an experienced craftsmen or project manager to learn that the decrease in design quality affects the performance of construction.

2. Increased use of disclaimer clauses – Modern contract documents contain many disclaimer clauses that attempt to deny responsibility for the sufficiency and accuracy of the detailed information contained in the project plans and specifications. Examples of disclaimer clauses include those that tell the contractor or subcontractor not to rely on the information contained in the contract specifications, or that the drawings are schematic and not specific in nature, or clauses that instruct that the contractor is responsible to see that all work is installed in accordance with local codes regardless of what is shown on the contract documents.

3. Shortened construction duration – Owners and developers have established the

importance of a short construction duration due to the cost of money and the small timeto-market windows of positive cash flows. This has increased the use of fast-track construction and caused plans to be sent out to bid much sooner than is appropriate causing a lack of coordination and inexactness in details. Moreover, the short duration can create a schedule that is unrealistic and raises the need for the stacking of trades to complete the work on time. The presence of trade stacking can amplify the impact of any changes that occur.

4. Increased risk – The current construction climate of small profit margins (industry average of two-three percent) is a result of the increase in competition for contracts. The current competitive environment precludes contractors from having adequate contingency to absorb costs arising from non-estimated conditions such as delay, poor quality designs, and excessive change orders. With no mode of impact dissolution, contractors are forced to dispute the project impact costs caused by owner actions through change orders or other disruptive activities.

These changing industry conditions have spawned several research efforts into developing a method to determine the loss of productivity as a result of change orders for a given project, most notably the Leonard Study¹⁰ and the CII-Hanna Study.⁸ The past research on the impact of change orders has primarily focused on general construction and the labor-intensive trades of electrical and mechanical construction. The current research will focus on the cumulative impact of change orders on labor productivity for a different and unique section of the construction industry: sheet metal.

Problem Statement

Sheet metal contractors are unique from most other forms of constructors in that they almost exclusively fabricate their own components, which is primarily duct. Other trades such as general civil, mechanical, and electrical procure materials, schedule a delivery, and install the components. A change affects the entire process but the brunt of the loss will be experienced during installation where a ripple impact can alter the productivity of the tradesmen. The affect of a change order on the procurement of a material may result in a time loss but any direct productivity loss by the contractor will take place on the jobsite.

A change for a sheet metal contractor will not only impact onsite construction but will also interfere in the fabrication aspects of the contractor. For example, a change to a ventilation component not only requires that the field alter its construction sequence but also that the fabrication shop altars the production schedule to assemble the changed component. The change in the fabrication schedule will impact the progression of other areas of the project that rely on the fabrication shop to deliver the necessary duct to the jobsite at the correct time. The ripple impact of change orders for sheet metal contractors includes not only the field operations but also the fabrication operations. The duality in the impact of change orders on two aspects of the contractor's firm may cause a cyclical impact where a change on site requires a change in the shop; thus requiring another change on the jobsite downstream in the project schedule.

Acknowledgement of the ripple effect of change orders differs between a contractor and a project owner. Contractors see it as an unpredictable aspect of change management while owners use standard contracts that include clauses which state a processed change order is for its full and total cost. The cumulative, unpredictable nature of multiple changes coupled with contractual wording that precludes a contractor from receiving financial adjustment often leads to disputes or litigation between owners and contractors. Hereto, the purpose of the present research was to quantitatively capture the unique impact of change orders on the productivity of sheet metal craftsmen, thereby providing the sheet metal industry with a valid measure of the impact of change on project efficiency.

Research Objectives

The purpose of this research was to quantify the cumulative impact of change orders on sheet metal labor productivity. This goal entails four objectives:

1. Investigate the characteristics of project impacted by change orders.

2. Develop a model that can quantitatively estimate the cumulative impact of change orders on a given sheet metal project.

3. Test the developed models for validity on the collected sheet metal projects.

4. Develop sheet metal industry benchmarks for various project characteristics that can be used to reduce the impact of change orders through better project planning and control.

Delta Approach

In the quantification of the cumulative impact of change orders on a contract, the essential quantity to be identified is the lost productivity due to the ripple effect of the inefficiencies and disruptions caused by numerous change orders. On a construction project, productivity can be analyzed on a micro or a macro scale. A micro-analysis looks at a specific activity of a project, while a macro-analysis considers the project holistically. For the purposes of quantifying cumulative impact, the complex and interrelated nature of the productivity loss dictates that a macro-analysis be employed. To determine productivity under a macroanalysis, earned (estimated) hours are taken as the measure of output and expended (actual) hours are taken as the measure of input.

Employing the earned-to-expended definition of productivity, researchers have developed the term Delta as the essential quantity measuring lost productivity due to the cumulative impact of change orders. Delta is the difference between the total actual workhours worked by a contractor and the workhours that were reimbursed on given project. The total actual hours worked is equal to the hours required for the base contract plus the hours needed for the ownerapproved change orders. The reimbursed hours are equal to the original contracted (estimated) hours and the approved change order hours that were compensated for during construction. Delta can take a positive value or negative value. Positive values of Delta indicate that the actual productivity is less than planned or estimated productivity. Conversely, negative values of Delta are an indication of higher efficiency than originally anticipated or estimated. Figure 1 graphically displays the Delta concept.



Figure 1: The Delta Concept

A Delta may result from a contractor's inaccurate estimate, exceptional or poor performance, other contractor caused inefficiencies, and/or the impact of productivity-related factors such as change orders, weather conditions, work interruptions, etc.⁸ These components of Delta are shown in the portion of Figure 1 that elucidates the individual components of Delta.

Percent Delta

To be able to compare projects of varying size, it is necessary to normalize Delta as a percentage. This is done through the creation of Percent Delta. Percent Delta is simply a project's Delta divided by actual workhours consumed to complete the project.⁸ As a mathematical expression, Percent Delta (%Delta) is given in Equation 1, below:

Beyond allowing projects of varying size be directly compared, the Delta approach represents the cumulative impact of the cause and not just the effect.⁸ The strength of the Delta approach is its use of contract hours instead of contract dollars in the measurement of loss. This allows projects to be compared regardless of location of construction, year of completion, and size. One shortcoming of the approach is its failure to account for off-project costs. Offproject costs may accrue when contractors are forced to reallocate resources from other projects to bring a distressed project under control. Consequently, the loss of productivity or even profit from a secondary project is not considered in the analysis of the losses of an impacted project under the Delta approach.⁸

Research Methodology

The first step in the research was to identify the problem of cumulative impact and develop a detailed definition of the cumulative impact of change orders beyond what past research has developed. This was accomplished through contact with a major

%Delta = <u>Total Actual Direct Labor Hours - (Estimated Labor Hours + Change Order Labor Hours)</u> Total Actual Direct Labor Hours

Equation 1.1

contracting organization and a review of the available literature that quantifies the impact of change orders. Once this was accomplished, the primary research hypothesis was developed after the need for a tool to accomplish cumulative change order impact estimates was identified by the construction industry. In addition, secondary research hypotheses were created after the review of literature and multiple interviews with industry professionals. The primary research hypothesis was as follows:

It has been observed and established in previous research that multiple change orders have a cumulative effect on the productive performance of construction craftsmen through multiple inefficiencies. It is hypothesized that the productive impact of these inefficiencies can be reasonably estimated on an individual sheet metal project basis using observed project characteristics and conditions.

Since no data currently existed that could be used to test the research hypothesis and develop a model to quantify the impact of change orders on sheet metal construction, new data had to be collected. A research questionnaire was generated using available past research, characteristics of the sheet metal industry, and the construction knowledge and experience of industry professionals and the research team. After its formulation, the research questionnaire underwent pilot testing and several iterations. After a suitable final questionnaire was formed, it was distributed to sheet metal contractors located throughout the United States. The list of sheet metal contractors was compiled by the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) and considered the responding contractor's ability and likelihood to have the needed project data recorded and available.

The next step in the methodology was to analyze the collected data. Because this research is the first industry approach to quantifying the cumulative impact of change order for sheet metal contractors, a regression model was chosen as the first method to develop the impact estimation tool. Utilizing the research data, the developed impact model was stringently validated to ensure its applicability to the sheet metal industry.

One of the objectives of the research was to develop sheet metal industry benchmarks to allow for better project planning and control. This was accomplished through the creation of manpower loading and project S-curves. This portion of the research was intended only to enhance the sheet metal industries knowledge of average project characteristics as determined from the collected dataset.

2 CUMULATIVE IMPACT

The fundamental idea behind the cumulative impact of change orders is that the cumulative disruptive effect of multiple changes causes a cost to a contractor beyond those attributable to the individual changes themselves.⁹ Furthermore, the greater cost is not identified in the labor, material, and equipment (direct costs) needed to make the changes themselves, but in the loss of productivity on both the changed and unchanged work due to the synergistic disruption of the unreasonable number of changes.⁶ The synergistic disruption is essentially the effect that the changes have on the flow of work; this is also commonly called the "ripple effect" that change orders cause through a project.^{14,8} The "ripple effect" or synergistic disruption causes a productivity loss on a project because:

"Foremen and journeymen who know what they are doing, what they will be doing next, and how their activities relate to the successful completion of a project develop a 'job rhythm.' Labor productivity is at its optimum when there is good job rhythm. When that job rhythm is disrupted, the productivity of those engaged in the interrupted work is definitely impacted and the effect can spread to other concurrent activities as well."⁵

Disruption is defined as any change in the method of performance or planned work sequence contemplated by the contractor at the time that the project was bid that prevents the contractor from actually performing in that manner.⁴ In the instance of change orders, the job rhythm is disrupted and a productivity loss is experienced on both changed and unchanged work due to a variety of change caused reasons. This productivity loss causes and impact cost to the contractor.

The impact cost, or the cost to the contractor that is beyond what can be reasonably estimated, is the change orders' unforeseeable effect on the changed and unchanged work currently being performed or work that is as of yet to be performed (a.k.a. distant work).¹ Moreover, the impact costs themselves are the additional costs occurring as a result of the loss of productivity; loss of productivity is also termed inefficiency. Thus, impact costs are simply increased labor costs that stem from the disruption of labor productivity resulting from a change in working conditions caused by a contract change.

Summarily, the cumulative impact of change orders can be defined as the costs associated with impact on distant work, that are not readily foreseeable or, if foreseeable, not as readily computable as direct impact costs. The primary source of such costs is the sheer number and scope of changes to the contract. The result is an unanticipated loss of efficiency and productivity that increases the contractor's performance costs and usually extends his stay on the job.¹³

Sheet Metal Contractor Data

For the research, 114 sheet metal contractors were contacted to complete the questionnaire. From these contractors, 38 sheet metal projects impacted by change orders were collected. Of the 38 collected projects, 28 met the research scope set forth at the outset of the project. The research scope considered only those projects that had change orders as there primarily source of productivity loss, experienced at least a 5% loss of productivity, experienced at least 5% change due to change orders, were at least 2000 total workhours in size, and were tradition plan-and-spec lump sum projects.

For the collected projects, 48% were institutional, 25% were commercial, 19% were specialty facilities (stadiums, unique

religious centers), 3% were industrial, 3% were residential, and 2% were manufacturing. Of the work performed, 89% was HVAC installation. Also, the average project size was 54,600 workhours, with a maximum of 190,050 workhours and a minimum of 9,900 workhours. The average productivity loss experienced was 22.5%, the average amount of change was 27%, and the average second lowest bidder was only 4.1% higher than the winning contractor.

Hypothesis Development

As stated in Section 1, the primary research hypothesis was that project inefficiencies due to change order impact could be reasonably estimated. In addition to the primary hypothesis the research team sought to fundamentally contribute to the knowledge of construction by capturing the factors that impact project performance (Research Objective #1). Therefore, two additional sets of hypotheses (for a total of 23) were tested: Hypotheses of impact on productivity and hypotheses of impact on percent change order workhours. For the hypotheses of impact on productivity, Percent Delta was used as the correlative variable. Likewise, for the hypotheses of impact on percent change order workhours, Percent Change (change order workhours divided by budgeted workhours) was used as the correlative variable. Tables 1 and 2 present the results, an outcome of "Pass" indicated the hypothesis statement cannot be rejected.

The research hypothesis were formed from an examination of past literature, the research team's experience, and input from sheet metal professionals. The testing sought to not only prove certain industry conceptions but also to disprove some industry perceptions. For example, often it is believed that if a contractor is too low on an estimate and leaves significant "money on the table" he will inevitably file for more change orders and extra work. The research disproves this belief (Hypothesis #18).

| Table 1: | Hypotheses of | Impact on | Productivity |
|----------|---------------|-----------|--------------|
|----------|---------------|-----------|--------------|

| Hypothesis | | With % Delta | | |
|------------|---|--------------|---------|---------|
| Test No. | Hypothesis | Correlation | p-value | Outcome |
| 1 | The greater percentage of change order hours experienced on a project the larger the loss of productivity | 0.439 | 0.053 | Pass |
| 2 | Larger projects experience smaller percentage losses of productivity due to change orders | -0.325 | 0.098 | Pass |
| 3 | Projects of new construction will be less impacted by change than those of addition/expansion or renovation work | 0.356 | 0.068 | Pass |
| 4 | The greater percentage of project hours worked in beneficial occupancy, the greater the loss of productivity due to changes | 0.371 | 0.057 | Pass |
| 5 | Projects with larger average hours worked per week per worker (greater use of overtime), will experience greater productivity loss | 0.339 | 0.090 | Pass |
| 6 | Priority of work sequencing in favor of sheet metal contractors reduces the impact of change orders | 0.451 | 0.018 | Pass |
| 7 | Projects with a greater percentage of designs complete at the start of construction have smaller losses of productivity due to change orders | 0.217 | 0.274 | Fail |
| 8 | Projects with a formal Architect/Engineer's coordination of design documents have smaller losses of productivity due to change orders | -0.783 | 0.000 | Pass |
| 9 | The greater percentage of a project manager's time spent on the project, the smaller the impact of change orders | -0.220 | 0.279 | Fail |
| 10 | The use of manpower loading graphs in project control relate to projects of less productivity loss | -0.357 | 0.067 | Pass |
| 11 | Projects where installed quantities were tracked experience less impact from change orders | -0.349 | 0.080 | Pass |
| 12 | Projects with larger percentages of change orders occurring during the peak manpower usage experience greater productivity loss | 0.355 | 0.070 | Pass |
| 13 | The longer the processing time for requests for information (RFIs), the greater the loss of productivity | 0.040 | 0.843 | Fail |
| 14 | The greater the severity of piecemeal work due to changes, the greater the loss of productivity | -0.223 | 0.264 | Fail |
| 15 | Projects with more restrictive component spacing experience a greater loss of productivity due to changes | 0.062 | 0.758 | Fail |
| 16 | Projects with a greater percentage of change order hour due to design error experience a greater loss of productivity due to changes | 0.402 | 0.038 | Pass |

Table 2: Hypotheses of Impact on Percent Change Order Workhours

| Hypothesis | | With % C | hange | |
|------------|--|-------------|---------|---------|
| Test No. | Hypothesis | Correlation | p-value | Outcome |
| 17 | Projects of new construction have less change than those of addition/expansion or renovation w ork | -0.251 | 0.207 | Fail |
| 18 | Projects w ith a larger difference betw een the w inning and second low est bid have more change | 0.021 | 0.927 | Fail |
| 19 | Projects w ith an ow ner experienced w ith the type of construction in question have less change | 0.087 | 0.667 | Fail |
| 20 | Projects with a greater percentage of designs complete at the start of construction have less change | 0.016 | 0.938 | Fail |
| 21 | Projects with project managers with more experience as a PM have less change | -0.376 | 0.053 | Pass |
| 22 | Projects with quicker request for information processing time have few er changes | -0.296 | 0.134 | Fail |
| 23 | Projects w ith quicker change order processing time have few er changes | -0.439 | 0.022 | Pass |

³ QUANTIFYING IMPACT

As mentioned in Section 1, when first analyzing a new field of study such as the cumulative impact of change orders on sheet metal construction, it is the favored scientific approach to use an analysis technique that is well established in precedent research and preferably simple in its application. Regression analysis is such a technique and was an appropriate first approach for developing a model of quantification. To develop the regression model, first a correlation analysis was performed on over 90 variables contained in the dataset. After the initial exploration of variable correlations, an iterative approach to model formulation was performed. Using a variety of

techniques, measurements, and diagnostic tests, a final model was fitted that was able to estimate the dependent variable of %Delta.

The Final Model and Validation

The final model contains five variable identified as significant through the testing methodology described above. The regression equation to estimate the magnitude of the impact of change orders on sheet metal labor productivity is as follows:

Table 3 gives the definition of each of the independent factors listed in Equation 3.1. The numbers in column 3 of Table 3 should be considered the limits of the variables in the model. Projects with variables that fall outside these limits lessen the accuracy of the %Delta calculation

%Delta = 0.377 + 0.136 * %Change + 0.111 * Type of Work – 0.212 * %Extension – 0.213 * A/E Coord – 0.112 * %OFE

Equation: 3.1

| Variable (1) | Description (2) | Limits (3) |
|-----------------|--|---|
| %Change | %Change =Approved Change Order Labor Hours + Credit Change Order Labor Hours Estimated Labor Hours | 0.05 to 1.09 |
| Type of Work | There are two possible types of work: 0 = New Construction 1 = Addition, Expansion, or Renovation | 0 = New Const. 1 = Add., Exp., or Reno. |
| % Extension | %Extension = <u>Actual Project Duration - Original Contract Duration</u> , in weeks Actual Project Duration | -0.08 to 0.65 |
| A/E Coord | Did the A/E conduct a formal coordination of the design documents? | 1 = Yes $0 = No$ |
| %OFE | Amount of owner-furnished equipment as a percentage of the project workhours (for installation) | 0.00 to 1.00 |

 Table 3: Variable Description and Limits

Due to the limits in the number of collected projects, the data was stringently validated via a number of methodologies. First, the model was examined for multicollinearity by examining the variance inflation factors. The model was also validated by randomly dividing the data into seven subsets. The model was then re-fit using 85% of the data and tested against the remaining 15% of the projects. This resulted in an average absolute value difference of only 4.3% Delta between the actual loss and the estimated loss using the model.

The model was also systematically crossvalidated one project at a time, where one project was removed and then tested against a model of the remaining data. The average difference in the actual and estimated Deltas was only -0.1%. The model was also validated for differences in project size, percent change, project location, and for each variable. The results were all completely satisfactory to the research team and two outside professional statisticians.

An Example Application of the Model

To demonstrate how Equation 3.1 should be utilized, the following scenario is presented. Sun Badger Sheet Metal Construction Company entered into a contract to install the HVAC requirements of a new office building for Gizmo, Inc. (New Construction gives a Type of Work value of 0). Using the contract drawings and specification developed and formally coordinated by Arbco Engineering, Sun Badger Construction estimated it would take 11,750 workhours to complete the project. Also, Gizmo, Inc. provided a portion of the building equipment needed for the HVAC work equating to 20% of the total equipment installation hours.

Throughout the project, Gizmo, Inc. approved 1,347 change order workhours. Due to the increase in work the contractor found it necessary to implement overtime and overmanning to stay on schedule and not have a project extension. At the end of the project, Sun Badger Construction adds up its total labor hours and arrives at 17,245 workhours, a loss of 4,148 hours or 24.1%. The contractor has reserved his right to make a claim for impact that the changes may have had on his labor efficiency. Sun Badger submitted the 17,245 workhour total to Gizmo to be reimbursed for the cumulative impact of change orders. Gizmo, Inc. agreed that the changes may have impacted the project and lowered the labor productivity of the contractor but not to the extent that Sun Badger claimed. Because both parties agreed the project was impacted, they decided to use the SMACNA New Horizon Foundation's model for quantifying change order impact. The project data are inserted into the equation to arrive at an estimate of change order impact.

| Variable (1) | Coefficient (2) | Value (3) | Product (4) |
|---|-----------------|--------------|-------------|
| Constant | 0.377 | 1 | 0.377 |
| Percent Change (CO workhours/ Est. workhours) | 0.136 | 0.115 | 0.0156 |
| Type of Work | 0.111 | 0 | 0 |
| %Extension | -0.212 | 0.000 | 0.000 |
| A/E Coordination | -0.213 | 1 | -0.213 |
| %Owner furnished Equipment | -0.112 | 0.200 | -0.022 |
| %Delta = | | | 0.1572 |

Table 4: Example Application Calculation of %Delta

Inserting the project information into Equation 3.1 yields:

% Delta = 0.377 + 0.136 * %Change + 0.111 * Type of Work – 0.212 * %Extension – 0.213 * A/E Coord – 0.112 * %OFE % Delta = 0.377 + 0.136*0.115 + 0.111*0 – 0.212*0 – 0.213*1 – 0.112*0.2 % Delta = 0.1572

In other words the parties find that the %Delta for the project was predicted to be 15.72% of the total actual workhours. This corresponded to 2,711 extra workhours that could be attributed to changes, in addition to the 13,097 workhours (estimate + approved CO). While the 15,808 workhours is less than the submitted 17,245 workhours, Gizmo, Inc. is not totally convinced that the number is exactly correct. The two parties are able to use the estimated value, however, as a benchmark.

Findings

It is important to remember when applying any equation, that to acquire accurate results, one must operate within the limits of the parameters used when developing the equation. The limits of the model (Equation 3.1) are defined in column 3 of Table 3. Utilizing this model with values that are outside these limits may produce inaccurate results.

In addition to quantifying impact, the research also contained the objective to develop project control tools and industry benchmarks that can be used to help reduce the loss of productivity incurred from change orders or any project inefficiencies. These project control tools and industry benchmarks are presented in the next section.

PROJECT CONTROL AND INDUSTRY BENCHMARKS

Management of a construction project is one of the most challenging managerial assignments in the industrial world. In a short period of time upon the award of a contract, a project manager or superintendent must finalize the preliminary plans, o rder materials and equipment, e rect support facilities, and recruit and mobilize a labor force.¹² Then, during construction, the manager is confronted with making a profit despite the vagaries of weather, material deliveries, regulations, and changes while guiding the efforts of a labor force. Consequently the need for tools to assist in project control is p a ramount in the construction industry, especially for labor-intensive specialty contractors such as the electrical, mechanical, and sheet metal trades. These labor-intensive t rades typically consume between 33% and 55% of the total project budget in labor cost,⁸ which is the most variable and riskiest project budget component. Having tools to manage the work force is often crucial to project success and can become even more important when a project is confronted with a large amount of changes, as change orders can have a particularly negative effect on labor productivity.

A myriad of project control tools and methodologies have been developed; however, this section will focus on two techniques that have proven to be effective in managing labor forces, the manpower loading curve and the project S-curve.

Manpower Loading Curves

Manpower loading for a project is the relationship between the number of workers onsite and the project duration. Manpower loading curves present this relationship graphically with the number of workers onsite as the y-axis and the percent project duration, running from 0-100%, on the x-axis. The simple relationship contained in a manpower loading curve is an extremely powerful tool as it shows a project to be contained in three stages: build-up, peak, and rundown.

Figure 2 shows a normal, unimpacted sheet metal project manpower loading curve as developed from over 400 project data points. The y-axis is the % Manpower of the Average, this was used to normalize the data collected from projects of different manning levels. As a result, 100% on the y-axis equals the project's average manning level; moreover, consider a project with an average of 8 workers and a peak of 15 workers. For Figure 2, 8 workers would be equal to 100% on the y-axis and 15 workers would equate to 188% (15/8 * 100%) on the y-axis. The project manager would expect to reach the level of 15 workers at approximately 25% of the total duration. To use the equation at the top of Figure 2, simply insert the time in the project duration you wish to analyze. For example, if a project manager needed to have an estimate of his needed manpower (relative to the average) at 40% of the project duration, insert 0.40 as the x-variable in the % Manpower of Average equation.



Figure 2: %Manpower of Average Curve

To facilitate an easier, more accessible figure for use by contractors in the field, a trapezoidal approximation to the curve developed in Figures 2 is given on the following page in Figure 3. From the figure, a simple empirical relationship as an approximation to planned manpower loading and project control for sheet metal work on a construction project is:

- 1. The maximum on-the-job manpower is approximately 180% of the average manpower requirement.
- 2. The maximum on-the-job manpower first occurs after 20% of the total manpower requirement has been expended. This is the project manpower build-up.
- 3. The period of maximum on-the-job manpower accounts for 45% of the total manpower requirement. This is the project manpower peak.
- 4. The maximum on-the-job manpower first occurs when 20% of the project duration has elapsed.
- 5. The period of maximum on-the-job manpower occurs for 25% of the project duration.

 The remaining 35% of the project manpower is consumed across the final 55% of the project duration. This is the project manpower rundown.



Figure 3: Trapezoidal Approximation of Sheet Metal Manpower Loading

With an industry benchmark for the manpower loading of a typical project, a project manager possesses a control tool that can be used as a template to track actual project performance against. Any significant deviation from the industry standard either is an explainable unique project circumstance or is an early indicator of project distress. Large deviations from a planned manpower loading often are also indicators of project overmanning and schedule acceleration or compression, which can be caused by change orders and lead to productivity loss.

S-curves

S-curves, also referred to as Performance Curves³ or Progress Measurement Curves,⁷ are used widely in industry for controlling projects throughout the execution phases of the job. S-curves are indispensable to project management in reporting current status and predicting the future of projects. They also are constantly used in scheduling and planning for reporting actual, earned, and planned values and for resource loading various activities of a project.¹¹

Fundamentally, an S-curve represents the relationship between the project duration and the cumulative project completion, where completion is measured in dollars or workhours. The objectives of developing a project S-curve are:^{11,15}

- 1. To provide a fast method for determining the schedule of a project and the manpower requirements.
- 2. To facilitate project control by integrating cost and schedule.
- 3. To simplify resource loading of network activities.

To build the sheet metal industry's normal, unimpacted project S-curve, the same data for the manpower loading analysis was used. This entailed using the 400 data points from normal or planned sheet metal projects and adapting it for the construction of an industry S-curve. Using the planned workhours per week and the project duration, an S-curve for the sheet metal industry was plotted with percent duration on the x-axis and percent cumulative manhours on the y-axis. The d eveloped curve is shown in Figure 5. As for the manpower loading curve, the %Cumulative Manhours equation for the sheet metal S-curve is given at the top of the figure. The x-values are for a percentage of the d u ration inserted as a decimal (0.0 to 1.00).



Figure 4: Sheet Metal Industry S-curve

Use of the S-curve on a project will allow a sheet metal contractor to graphically control the cumulative progress of the project workhours or costs. The system can be a simple tracking of hours or an integrated earned value approach to project control. Whatever the method, any significant deviations from the standard S-curve may signify a project distress or unique condition. It is also suggested that sheet metal contractors use their own project records to develop manpower loading curves and project S-curves specific to their company. These will serve as even better control tools than the industry averages presented in this report.

5 RECOMMENDATIONS AND CONCLUSION

Because change orders occur on every construction project, managing them can make or break a project, especially in a labor intensive field like sheet metal construction. The research was undertaken to provide a quantitative model for both owners and contractors to use in determining the impact of change orders on sheet metal labor productivity. The research also sought to provide an analysis of factors that impact project performance and create project control tools and industry benchmarks to help manage those factors. The research team believes the research objectives set at the outset of the project have been reached successfully. In addition to reaching the research objective, recommendations or "best practices" are offered to the industry.

Recommendations

The following recommendations are for contractors, owners, and design professionals in the general construction industry, and specifically the sector of sheet metal construction. The recommendations are based on statistical testing and represent actionable items for the contract parties.

Recommendations to Contractors

- 1. When preparing a project estimate for sheet metal (HVAC) work, consider that projects of 35,000 total workhours or less are impacted more by changes than projects of a greater size.
- 2. Projects of renovation work or addition/expansion are impacted by changes more than those of new construction. When preparing an estimate (project or change order) an adjustment is recommended to compensate for this fact. Additionally, since it has been found that project managers (PM) with greater experience can reduce the percentage of change order workhours on a project, it is recommended that these PM's be assigned to contracts of renovation or addition/expansion work.

- 3. When preparing an estimate (project or change order) for work in a beneficial occupancy environment, an upward adjustment should be included to compensate for the greater impact of change orders in this work situation.
- 4. Specifically for sheet metal contractors, insist, if practical, that you be allowed to proceed with your installation through the building prior to the mechanical and electrical trades using the same component space.
- 5. Create and update a manpower loading graph for every project. This will help manage and reduce productivity losses from change orders (and other impacts).
- 6. Tracking percent complete via installed quantities results in reduced impact from change orders.
- 7. Be cognizant of the fact that change orders that occur during peak manpower usage have a greater impact on productivity. Specifically, change order estimates for work occurring between approximately 26% and 50% of the project completion should be adjusted upward.

Recommendations to Owners

- Understand that the greater percentage of change order hours on a project the larger the expected loss of productivity will be. Reduce the amount of change whenever possible.
- 2. Requiring contractors to work in a beneficial occupancy environment will result in greater losses of productivity. It is recommended that the use of beneficial occupancy be avoided whenever possible.

- 3. Require the architect/engineer to formally coordinate the design documents.
- 4. Require the contractor to prepare and update a manpower loading graph for the project.
- 5. Issuing change order work during the peak manpower usage of a contractor has a greater impact on productivity than change order work issued at other times in the project.
- 6. The greater the percentage of change orders due to design error the greater the loss of productivity. It is recommended that a formal review process of the designs for errors be conducted. Even a simple review such as a checklist of typical error prone items has proven to substantially reduce the occurrence of change orders.
- 7. It is not necessarily true that a larger difference between the winning and second lowest bid will result in more change orders. Assumption of distrust from an owner regarding a contractor in this situation is not statistically founded.
- 8. Processing change orders as quickly as possible reduces the total number of change orders for a project.

Recommendations to Architects/Engineers

- 1. Conduct a formal coordination of the design documents.
- 2. The greater the percentage of change orders due to design error the greater the loss of productivity. It is recommended that a formal review process of the designs for errors be conducted.
- 3. It is not true that having more contract documents complete at the start of

construction will help reduce project impacts from changes. It is recommended that instead of rushing design to complete drawings by a specified date, the architect ensure the quality of the design for as much of the project as possible and then complete the remainder of the design for work to come later in construction at a "reviewable" pace. This practice should be incorporated in future design contracts.

Conclusion

It has been determined that there is a strong correlation between the amount of change hours worked on a project and the loss of productivity (% Delta). As the amount of changed work increases, or if there is a significant amount of extra work during the peak manpower usage on a project, one is more likely to experience productivity loss. While the research team is confident in the developed model, it must be noted that it is best to use the results in conjunction with hard, project specific data, for example manpower loading curves and productivity tracking data. It is again suggested that both contractors and owners track manpower usage against an estimated manpower loading curve (such as the industry average given in Section 4). This will allow proactive steps to be taken to correct negative trends rather than waiting for the end of project. It is also recommended that the owner and contractor agree to utilize the developed model for change order conflict resolution prior to signing the contract. This would, as a minimum, provide a starting point for negotiations.

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