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SCHEDULE COMPRESSION EFFECTS ON LABOR PRODUCTIVITY

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EXECUTIVE SUMMARY

During a typical construction project, a contractor may find that the time originally available, or normally expected to perform its work has been severely reduced. To finish the project by the completion date, the contractor is forced to find a way to speed up the progress of its work, or "compress the schedule." By definition, when the contractor speeds the work up to compensate for the reduction in available time, the schedule is compressed. *Schedule compression*[1] poses a problem to contractors, because it negatively impacts *labor productivity*. This impact translates into lost profits for the contractor. Therefore, understanding how schedule compression affects labor productivity is crucial for increasing project performance, avoiding disputes, and maintaining sound financial status of one's company. For several trades, models have already been developed to quantify the loss of productivity resulting from schedule compression. Unfortunately, a similar model is yet to be developed for the sheet metal contracting trade.

To compress a schedule, contractors, including sheet metal contractors, accelerate the work in order to finish in the lesser time available. The most common way to compress the schedule is either to work longer hours (*overtime*), add more workers (*overmanning*), or implement multiple shifts (*shift work*). The goals of this study were to investigate how schedule compression affects sheet metal contractors' labor productivity, to quantify the effects of the three primary schedule compression methods (Overtime, Shift Work, and Overmanning) on sheet metal contractors' labor productivity, and to provide schedule compression recommendations to sheet metal contractors. These objectives were achieved by analyzing project data that had been collected from sheet metal contractors across the country. In this study, the labor productivity effects of overtime, shift work, and overmanning were investigated, and models that quantify the impact of each on the labor productivity of sheet metal contractors were developed.

The study results show that when overtime, shift work, and overmanning increase, labor productivity decreases. In this document, quantification models, graphs, tables, and case studies are provided to assist sheet metal contractors in understanding the labor productivity loss caused by overtime, shift work, and overmanning. Recommendations for the contractor are also provided at the end of the report for the purpose of helping to reduce the impact of schedule compression on labor productivity.

1 'Italicized words defined in glossary'

1 INTRODUCTION

Background

The construction industry is a highly competitive and volatile market. The Industry has earned this reputation by a variety of factors. One factor that seems to be prevalent in construction disputes is time. Tensions between owners and contractors often escalate when the issue of time arises. Driving this tension is the fact that time often equals money. Time savings can greatly improve profits, while a loss of time can lead to financial ruin.

As a result, time conservation is a prime concern for both the owner and the contractor. If a substantial delay or loss of time is encountered during a project, late completion will become a significant issue. When a project is extended beyond the original completion date, the owner may consequently lose business opportunities and income that would have been derived from a timely completion. To the extent that the contractor is responsible for the delayed completion, the contractor may be charged a penalty based on the liquidated damages clause in the contract. Clearly, timely completion is one of the basic objectives of the construction project since it will prevent these negative impacts from hindering the contractor and owner.

However, timely completion can often be accompanied by its own problems. Frequently, the owner will require the contractor to complete a project in a less than the normal time frame originally needed or will require additional work to be completed within the original time frame. Unforeseeable circumstances outside the control of the contractor may also cause a reduction of time available for completing the work. When these circumstances arise, the contractor is forced to accelerate its work progress in order to accomplish a "timely" completion for the owner. This act of acceleration accomplishes what is commonly known throughout the construction industry as schedule compression.

By definition, schedule compression is a reduction from the normal experienced time or optimal time typical for the type and size of project being planned within a given set of circumstance (Construction Industry Institute 1990). To successfully achieve the work in the reduced timeframe, schedule compression methods are implemented. The most common *schedule compression methods* are overtime, overmanning, and shift work. Although different in means, all of these schedule compression methods are established ways to accomplish more work in a reduced amount of time. Overtime consists of workmen performing over 40 hours per week, and in many cases working on the weekends. Overmanning occurs when additional workers in excess of the optimum number are ordered to work in an area. Lastly, shift work utilizes the concept of working multiple shifts to keep the work progressing above and beyond the normal eight-hour day. Depending on the circumstances, these three schedule compression methods can be used individually or in combination. Unfortunately, all three of these methods result in a decrease in labor productivity.

Exacerbating the problem is the fact that schedule compression is a common occurrence on construction projects. According to previous studies of a similar trade, more than 90% of electrical contractors have experienced schedule compression of their original or normal project duration (Noyce and Hanna, 1998). Oftentimes, a contractor is forced into schedule compression when numerous delays occur during project execution without the owner accordingly granting extra time. For example, on approximately three out of four construction projects, owners refuse to grant a time extension for delay (Leonard et al., 1988). As these facts indicate, contractors frequently experience schedule compression during project implementation.

Problem Statement

At first examination it may seem that schedule compression would be an effective solution for construction problems associated with time. Unfortunately, schedule compression negatively impacts the contractor's labor productivity. As a result, the occurrence of disputes and claims between owners and contractors rises when the labor productivity of the contractor is impacted. A decrease in labor productivity is especially alarming since labor costs are highly variable and represent a large percentage of a project's total installed cost. Therefore, understanding how and why the problem of schedule compression impacts labor productivity is essential for successful claims avoidance. In this way, the owner and contractor will be adequately informed on how schedule compression impacts labor productivity; and furthermore, the owner will realize that this impact comes with a cost.

Schedule compression can impact labor productivity in various ways. First, schedule compression can alter the planned sequence of activities and flow of resources, including labor, materials, equipment, and subcontractors. Research shows that when the orderly plan of a project is impacted by schedule compression, labor productivity can be seriously affected (Peles 1977, Borcherding 1980, Marchman 1988, Long 1988, Haneiko and Henry 1991, Thomas 1997). Secondly, schedule compression often requires activities to be accomplished concurrently in a limited working space. Frequently, more workers will be added to achieve completion, and oftentimes the work area will not be able to accommodate the increased number of workers or activities. A high density of workers in a limited work space results in site congestion, and thereby causes a labor productivity loss (US Army Corp. of Engineers 1979, Peles 1977, Marchman 1988, Long 1988). Thirdly, as the number of on-site workers increases, it is critical that a corresponding increase be made to the supervisory staff, materials, tools, and equipment. If the proper increases are not made, labor productivity may decrease. It is widely accepted in the construction industry that a dilution of supervision and a shortage of materials, tools, and equipment may lead to a productivity loss. (Peles 1977, Thomas 1997). There are many additional ways that schedule compression can affect labor productivity that have not been mentioned.

Clearly, when schedule compression occurs, labor productivity is impacted. This impact results in higher labor costs to the contractor. These costs come both in the form of direct labor costs and costs due to lost labor productivity. Direct labor costs incurred during schedule compression can be easily tracked. Therefore, direct labor costs are usually not disputable. However, loss of labor productivity costs can be very difficult to quantify and are often aggressively disputed by the owner. Unfortunately, the most significant portion of increased labor costs due to schedule compression is due to lost labor productivity. The cost of this lost labor productivity is one of the most prevalent types of damages found in construction claims. For successful recovery of the damages, contractors must prove that the work was accelerated, and that additional costs and lost labor productivity were incurred as a result. Unfortunately, courts and adminstrative boards frequently find that contractors fail to provide sufficient documents evidencing that the work was accelerated, and to establish a cause-effect relationship between schedule compression and the subsequent increased labor costs. Without demonstrating or quantifying damages, the additional cost of lost labor productivity cannot be compensated.

As the courts have ruled, loss of labor productivity from schedule compression is difficult to quantify. As a result, numerous trade organizations have developed productivity models to quantify the impact of common schedule compression methods on labor productivity. However, no such model has currently been developed for sheet metal contractors. In this study, the relationship between schedule compression and productivity loss for sheet metal contractors will be investigated and quantified through model development.

Objectives

As previously mentioned, labor costs typically represent the largest portion of the total construction cost (Hanna 2000). Therefore, understanding the impact that schedule compression has on labor productivity is crucial, because an increase or decrease in productivity will respectively reduce or raise labor costs in direct proportion. This reality applies to all construction trades; however, this study specifically focused on the trade of sheet metal contracting.

The objectives of this study were:

- To investigate the effects of overtime, overmanning, and shift work on the labor productivity of sheet metal contractors
- To quantify the impacts of schedule compression on the labor productivity of sheet metal contractors
- To develop a document that provides recommendations and appropriate uses of scheduling compression techniques for sheet metal contractors

Research Methodology

To efficiently develop a quality model for sheet metal contractors that would determine labor productivity impact from schedule compression, two key concepts were used: the *Delta Approach*, and the *Factors Approach*.

Delta Approach

On a construction project, productivity can be analyzed on a micro or a macro scale. A macro-analysis considers the project in its entirety, while a micro-analysis looks at a specific activity of a project (Hanna 1999). Ideally, the impact of schedule compression

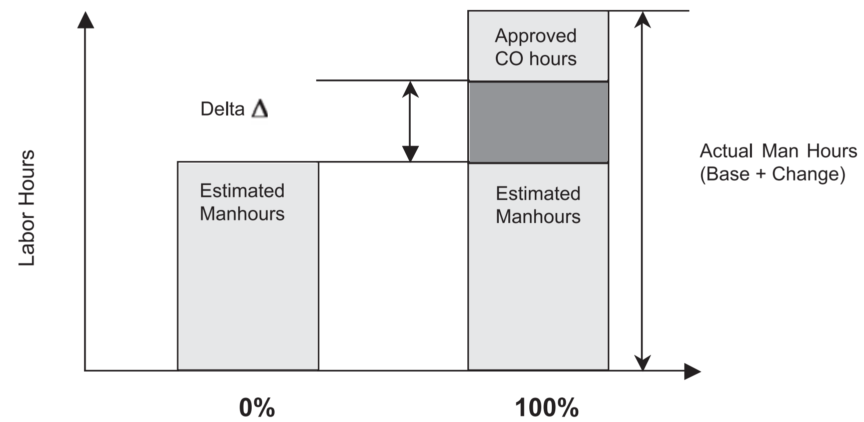

Figure 1: Concept of the Delta Approach (Hanna 1999)

on labor productivity should be considered by looking at the entire project as a whole. Since it would be difficult to quantify the impact of schedule compression on a project as a whole through micro analysis, macro analysis was adapted to determine the impact of schedule compression on labor productivity. The Delta Approach was developed to analyze the effect of schedule compression on labor productivity in macro scale.

Delta is defined as the difference between the actual labor hours expended to complete a project and the estimated base hours (including the approved change order hours). Delta can take a positive or negative value (Hanna 1999). A positive Delta value indicates that the actual productivity is less than the planned or estimated productivity. A positive Delta may result from a contractor's inaccurate estimate, poor performance, other contractor-caused inefficiencies, or from other factors, such as change orders, weather conditions, or work interruptions (Hanna 1999). On the other hand, negative values of Delta are an indication of higher efficiency than originally anticipated or estimated. Figure 1 shows the concept of the Delta Approach.

Figure 1 displays a project that has a positive Delta value. The contractor and the owner will both agree on the hours allocated to either the "estimated manhours" or "approved CO hours." However, the Delta hours will be heavily disputed as to their source. In the past, schedule compression studies have indicated that a certain portion of this Delta can in fact be attributed to a corresponding decrease in labor productivity.

% Delta

Delta is normalized as a percentage to be able to compare projects of varying size. This is done through the creation of *Percent Delta*. Percent Delta is simply a project's Delta divided by actual manhours expended to complete the project (Hanna 2000). Calculation of Percent Delta (*% Delta*) is given in Equation 1.

$$\% Delta = \frac{Actual\ Total\ Manhours - (Estimated\ Total\ Manhours + Approved\ Change\ Order\ hours)}{Actual\ Total\ Manhours}$$

Equation: 1

Factors Approach

Understanding the effects of schedule compression on labor productivity is quite difficult because the factors affecting labor productivity in a schedule compression situation are numerous. During schedule compression, a number of factors such as overtime, shift work, and overmanning may be impacting labor productivity. Accordingly, each of these factors contributes to a portion of the total productivity loss (Delta) experienced.

Both the Delta and Factors Approach concepts were used to develop models for sheet metal contractors that can be used to quantify the labor productivity impacts from using overtime, overmanning, and shift work.

2 IS IMPACT REAL AND COMPENSABLE?

Impact

Attempting to convince an owner that schedule compression negatively impacts a contractor's labor productivity, and should thereby be compensated, is not an easy task. However, numerous productivity studies have indicated that a decrease in labor productivity from schedule compression is a reality. As indicated earlier, several schedule compression methods are available to contractors in order to speed up the work progress: overmanning, overtime, and shift work. All three of these methods result in a decrease in labor productivity. For example, the adverse effects of overtime - premium pay and reduced productivity - sum, on average, to 300% of the straight time hourly rate (Smith 1987). Furthermore, for all industries in the United States, the total cost of shift work is estimated as nearly $77 billion, and approximately 84 % ($ 64.5 billion) of this total cost is due to reduced human performance at work (Colburn, 1997). As these studies indicate, when a schedule is compressed with basic methods; labor productivity decreases.

Case Studies

Apart from the academic acceptance of schedule compression and its impacts on labor productivity, there are many court cases that validate the existence of this issue. For example, in one particular case a contractor claimed that owner-caused delays had forced acceleration of the work in order to finish at or before the contract completion date (Siefford v. Housing Authority of Humboldt). In another case, the owner issued a change order requiring the contractor to complete the work five months earlier than the contract completion date for an early occupation (John F. Harkins Co., Inc. v. School District of Philadelphia). Clearly, these cases are classic examples of schedule compressions. In both cases, the contractor was forced to speed up its work and incur the resultant impact.

A third case shows the different viewpoints between owners and contractors on the project schedule. The project consisted of building a new stadium for a NFL team. Eleven months into construction, the contractor suffered a delay as a result of a tornado touch-down. The contractor was denied a time extension, forcing it to accelerate its efforts to overcome the tornado impacts. The contractor was not able to fully recover from the delay and resultantly achieved substantial completion on the project 28 days later than the contract completion date. In the end, neither party was satisfied with the outcome. The owner complained about late completion and the contractor litigated for compensable delay from schedule compression.

These examples show that schedules are often compressed and become a source of dispute between the owner and contractor. schedule compression impact on labor productivity is widely accepted in both the construction and academic realms. Research has proven that the impact is real, and the courts have allowed damages for impact to be filed.

Compensation

It has been established that the impact on labor productivity from schedule compression is real. However, this point is for naught unless the loss of productivity can be equitably compensated. Several scenarios of schedule compression exist, and each varies in its compensability.

If the reason for schedule compression is due to the contractor's mismanagement, or if the contractor simply accelerates the work because it felt it was behind schedule, the extra cost for compressing a project schedule would not be compensable. However, if the owner orders acceleration under the changes clause of the contract, or requests additional work to be performed within the original period of time, the owner will be responsible for the schedule compression impact on labor productivity. Furthermore, a contractor may request a time extension due to increased amounts of work, by change orders or otherwise, but the owner refuses to grant a time extension and insists that the project be completed by the original completion date. Under this circumstance, the contractor is entitled to compensation for its loss of labor productivity due to the resultant schedule compression. However, in such an instance, the contractor must be able to demonstrate certain key elements to recover damages: an owner directive that accelerated the work, an owner denial of extra time, and the increased cost of contractor performance.

Data Collection

Data from sheet metal contractors was required to validate that the impact that schedule compression has on sheet metal contractors' labor productivity is real. This data was collected for the purpose of developing models that would be able to quantify the impact and assist the contractor in recovering damages from productivity loss. To see the effect of schedule compression on labor productivity, the research team collected project data and analyzed it. Prior to data collection, the team hypothesized that selected factors could influence schedule compression during the execution of a construction project. Therefore, the research team developed a draft questionnaire that would provide data on these factors. The development of the questionnaire included multiple iterations before a final version was established. This development was performed via review of previous literature and research, a conference held by SMACNA, and phone interviews with contractors. After the various inputs were incorporated, the survey was sent to the University of Wisconsin - Madison Survey Center and reviewed for understandability, readability, proper sequencing of questions, and ease of completion.

After the Survey Center's review, a pilot study was conducted to determine how easily the draft questionnaires could be answered and if the data collected would be useful for achieving research objectives. After reviewing the resultant data and talking to the participating contractors, the research team developed the final questionnaires. The final questionnaires were then distributed to sheet metal contractors across the country and followed-up with phone calls and e-mails. Project questionnaires were subsequently collected over a period of 18 months.

Through the data collection process, various facets of sheet metal projects were tabulated and reviewed. The information included project type, project size, type of owner, project delivery method, contractor's role, type of contract, contractor's project management practices, productivity information, and the project schedule, including estimated and actual manpower loading graphs. All factors, including productivity loss and project size, were defined by labor hours instead of labor costs. This was done because labor costs may vary from project to project. By using labor hours, all projects could be combined into a single database of their geographic area, time of completion, and size.

Through the collection and analysis of the survey results, it was clearly seen that sheet metal contractors' labor productivity is impacted through schedule compression.

Summary

Schedule compression has been proven to result in a real and compensable impact on labor productivity in the construction industry. Through data collection, it was validated that this impact also specifically exists for sheet metal contractors. The subsequent phase in the research was to quantify this established impact.

3 QUANTIFYING THE IMPACT

Introduction

After the impact of schedule compression on the labor productivity of sheet metal contractors had been validated, the next step was to quantify the impact through analysis of the data. As expected, the data indicated that the most common initial reaction of sheet metal contractors to schedule compression is to increase on-site manpower. As previously discussed, this may be done by using one of three schedule compression methods, or a combination of the three: working longer hours (overtime), adding more workers (overmanning), or implementing multiple shifts (shift work). It should be noted that the schedule may also be compressed by focusing on the activities along the critical path, adjusting the relationships between activities to create more overlap, splitting activities to create parallel activities, or thinking creatively about project implementation. However, in this study only the effects of the three most common schedule compression methods on labor productivity were investigated and quantified: overtime, overmanning, and shift work.

OVERTIME

Background

Overtime is defined as workhours in excess of 40 hours per week. Overtime is often preferred over shift work or overmanning, because it can produce the necessary higher rate of progress without the coordination problems realized with shift work or the congestion problems associated with

$$(Average\ Hours Worked\ per Week = \frac{Total\ Actual Workhours}{Project\ Duration (weeks)\ X\ Average\ Numbers\ of\ Workers})$$

Equation: 4

overmanning. Compared to overmanning and shift work, utilizing overtime is relatively easy since the contractor does not need to find more qualified workers and there is generally little resistance to its implementation (Noyce and Hanna 1997). Overtime is not only used for schedule compression, but is often used for other purposes. For example, overtime may be scheduled in order to maximize equipment use, take advantage of good weather, avoid penalties for late completion, or achieve bonus clauses. Furthermore, overtime can be scheduled to attract sufficient manpower and skilled craftsmen to the project, especially when a skilled labor shortage occurs in the market or the job site is remote from the main economic area. Regardless of the reason for its implementation, overtime will always impact labor productivity.

Quantifying the Impact of Overtime on Labor Productivity

To quantify the impact of overtime on sheet metal contractors' labor productivity at the macro level, *%Overtime* was considered. *Percent overtime* (%Overtime) is defined as the total overtime manhours worked on a project divided by the estimated total manhours (Equation 2). Alternatively, %Overtime can be calculated as the difference between average hours worked per week (from Equation 4 or project records) and scheduled hours worked per week, usually 40 hours per 5-day week, divided by scheduled workhours per week (Equation 3).

$$\%Overtime = \frac{Total\ Overtime\ Manhours}{Estimated\ Total Man\ hours}$$

Equation: 2

OR

$$\%Overtime = \frac{Average\ Hours Worked\ per Week - 40}{40}$$

Equation: 3

A high value for %Overtime indicates that a large amount of overtime was used on the project. Measuring overtime as a percentage of total estimated manhours allows for a straightforward determination of the effects of overtime on labor efficiency, instead of measuring loss of labor productivity in terms of weeks or months like many typical labor productivity models.

In the next phase of quantification, *linear regression* analysis was performed on the data collected from the survey. A resultant model was developed by which a productivity loss due to overtime can be predicted. The following equation (Equation 5) and corresponding graph (Figure 2) resulted from the analysis.

$$Productivity\ Loss = 0.06804 + 0.34257\ \%Overtime$$

Equation: 5

Equation 5 allows a sheet metal contractor to calculate its productivity loss by simply inputting %Overtime experienced on the project of interest. Since the range of

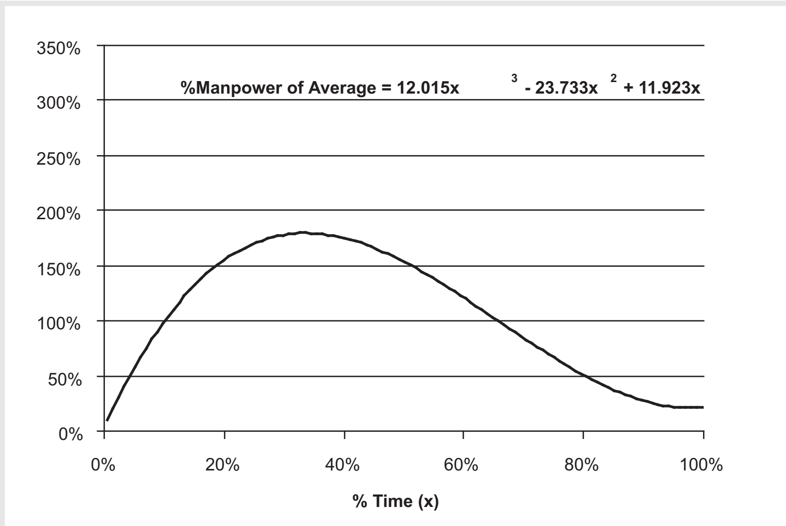

Figure 2: Effects of Overtime on Labor Productivity

%Overtime used for this analysis was from 5% to 50%, it is not recommend that Equation 5 be applied to projects where %Overtime is higher than 50%. If % Overtime is less than 5%, study results indicate that the amount of overtime is not significant enough to impact productivity. The project size also limits the applicability of Equation 5. The acceptable ranges for both project size and %Overtime are:

Project size: 2,000 manhours to 150,000 manhours
%Overtime: 5% to 50%

Therefore, it should be noted that for projects that fall outside of the ranges of either project size or % Overtime, the Overtime Equation is not applicable. Furthermore, the loss calculated by the Overtime Equation only applies to the hours worked during the time of excessive overtime use.

An Example Application

To illustrate the Overtime Equation, an analysis of project data supplied by a sheet metal contractor from Minnesota will be examined. The Minnesota project was commercial in nature and experienced schedule compression as a result of delays by the general contractor. To compensate, the sheet metal contractor implemented overtime to complete the project as originally scheduled. At completion, the sheet metal contractor had worked 8,811 total actual manhours. The original estimate, plus approved change orders, summed to 7,340 manhours. Of these hours, 500 manhours could be attributed to approved change orders, and 6,840 manhours made up the originally estimated manhours. Therefore, a productivity loss (Delta) of 1,471 manhours was experienced by the sheet metal contractor. The project record showed that rigorous overtime was used on the project, primarily between Week 12 and Week 23. During this period, the total manhours expended were

5,892 hours, and the total overtime manhours expended were 1,259.5 hours. Thus, % Overtime experienced was 18.4% (1,259.5 divided by 6,840). Inserting the % Overtime of 18.4% (0.184) into Equation 5, a productivity loss of 0.131, or 13.1% is yielded. Multiplying 0.131 by the total actual manhours used between weeks 12 to 23, which sums to 5,892 hours, gives a productivity loss of 772 manhours due to overtime (0.131 x 5,892 = 772 manhours). As a result, of the 1,471 manhours that were lost during construction, 772 manhours can be attributed to labor inefficiencies caused by overtime. The remainder of the hours lost, 699 manhours, can be attributed to other factors, such as the contractor's inefficiencies, stacking of trades, and poor field management.

OVERMANNING

Background

Overmanning can be defined in two different ways. First, overmanning can be defined as the situation where a number of workers greater than the optimal crew size are used. The optimal crew size is the minimum number of workers required to perform the task within the allocated time frame (US Army corp. of Engineers, 1979). Secondly, overmanning has occurred if the ratio of the actual peak number of workers divided by the actual average number of workers of a particular trade is greater than 1.6. In this study, the latter definition was adapted. Overmanning has an advantage over overtime and shift work in the aspect that it can produce the necessary higher rate of progress without the physical and mental fatigue associated with overtime or the coordination problems realized with shift work. Unfortunately, a loss of labor productivity will still be experienced if overmanning occurs.

Impact of Overmanning on Labor Productivity

Productivity losses due to overmanning result from a variety of circumstances stemming from schedule compression. In general, overmanning primarily creates inefficiencies due to physical conflict. This conflict results from a high density of workers. The subsequent congestion makes it extremely difficult for each particular tradesman to perform efficiently. Coordination and control of the overmanned crew also becomes more difficult. A dilution of supervision may occur, and materials, tools, and equipment shortages may also result. Furthermore, as the on-site work force increases, engineering questions and requests for clarification may not be provided in a timely manner due to a greater demand within a given period. The demand for additional labor may also introduce less productive workers to the jobsite. This results in poor quality of work, which requires an additional increase in supervision. An increase in the labor force will also increase overhead costs. In addition, more workers will have to spend time familiarizing themselves with the job. This will cause a further loss in productivity due to the loss of the *learning curve effect*, whereby new workers will not function at estimated efficiency until the second or third week (Horner and Talhouni 1995, Smith 1987, Brunies and Emir 2001). Overmanning impacts labor productivity in various ways, and its quantification is crucial to aid sheet metal contractors in recovering their resultant damages.

Quantifying the Impact of Overmanning on Labor Productivity

The indicator of overmanning is the ratio of the number of workers of a trade at peak and the average number of workers of a trade throughout the project. This ratio is shown below as Equation 6. If the peak over average ratio is greater than 1.6, it can be concluded that the project experienced overmanning. However, if the *peak over average ratio* is equal to or less than 1.6, then the project did not experience overmanning. Unlike stacking of trades, which considers all the workers on the site from all trades, overmanning deals with only one particular trade. Therefore, the number of workers at the peak and the average number of workers are only for the trade being analyzed. In this study, that trade is sheet metal contracting.

Two variables, the ratio of actual peak manpower over average manpower and the actual peak manpower, were included in the final model by which the impact of overmanning on sheet metal contractors' labor productivity can be predicted. The results, developed through linear regression analysis, and shown as Equation 7, are furthermore illustrated in Figure 3, where APM = Actual Peak Manpower.

$$\text{Peak over Average Ratio} = \frac{\text{Number of Sheet Metal Workers at Peak}}{\text{Average Number of Sheet Metal Workers}}$$

Equation: 6

$$\text{Productivity Loss} = -0.305 + 0.116 * \text{Act. Peak/Avg} + 0.163 * \text{Log (Act. Peak)}$$

Equation: 7

The Overmanning Equation is valid for projects only within the ranges of data used to formulate the model. The applicable ranges are:

Project size: 700 manhours to 208,000 manhours
Peak over Average Ratio: 1.7 to 3.8
Actual Manpower at Peak: 4 to 50

For projects that fall outside of the ranges for project size, Peak over Average Ratio, or Manpower at Peak, the Overmanning Equation is not applicable. It should also be noted that the losses calculated by the Overmanning Equation only apply to the total hours used during the time of overmanning.

An Example Application

To illustrate the Overmanning Equation, an analysis of project data supplied by a sheet metal contractor from St. Louis, Missouri, will be examined. The project began in January 2002, and was scheduled to end in May 2003. The sheet metal contractor was asked to complete the HVAC scope of the work by the end of January 2003. Originally, the HVAC scope was scheduled to conclude with the rest of the project in May 2003. Therefore, the sheet metal contractor experienced severe schedule compression, and had to add more workers to meet the deadline. At completion, the project had experienced a Delta of 4,600 manhours. The manpower loading graph of the project shows that severe overmanning was experienced between weeks 16 and 50 (almost the entire project). The actual peak manpower was 15 and occurred during the 40th week. The actual average manpower over the course of the project was 6.7. Therefore, the actual

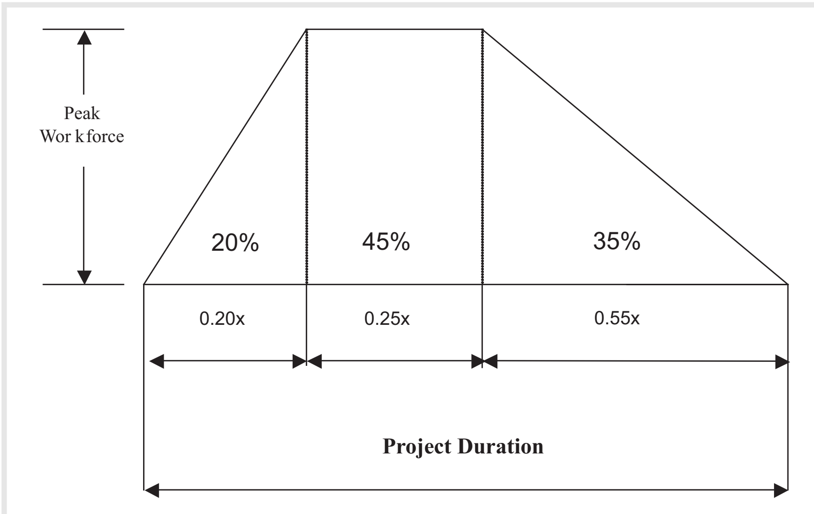

Figure 3: Effects of Overmanning on Labor productivity

peak over average ratio is 2.24. Since this value is greater than 1.60, overmanning was indeed present. Additionally, the project size was 14,781 total labor hours. By inserting values into the overmanning model, a productivity loss of 0.1465 (14.65%) is obtained. However, this loss percentage is only applicable to the portion of the project impacted by overmanning. Applying the results of the overmanning model, 14.65% is multiplied by the portion of the project impacted by overmanning, week 16 to week 50. Project records showed that a total of 11,694 manhours were spent during these weeks. Multiplying the result of the overmanning model, 0.1465, by the 11,694 manhours gives a productivity loss value of 1,713 manhours. This loss can be attributed to the loss in productivity from overmanning. The remainder of the hours lost, approximately 2,887, can be assigned to other factors such as stacking of trades, contractor's inefficiencies, and poor field management.

SHIFT WORK

Background

Shift work is defined as the situation where hours are worked by a separate crew after the first workforce of the same trade has retired for the day. Shift work is similar to overtime in the sense that more hours are worked during a day, but in shift work the additional work is undertaken by different workmen. Shift work is sometimes preferred over overmanning and overtime, because it can produce the higher rate of progress necessary without the immediate fatigue problems of overtime, or the congestion problems realized with overmanning. In addition, premium payment for a second shift is typically lower than that of overtime premium. However, like overtime and overmanning, shift work will impact labor productivity when used to compress the schedule.

Impact of Shift Work on Labor Productivity

Unfortunately, with shift work there is no single point of responsibility for the progress and quality of the work; and therefore, a period of wasteful overlap is often necessary for a smooth change-over. Additional problems with shift work include an increase in the unavailability of timely administrative decisions from higher management, the lack of worker coordination, absenteeism and turnover, errors and accidents, accident rates, and noise impacts to nearby residents.

Penkala (1997) and Hung (1992) report some of the common problems associated with shift work: little cooperation between shifts, inconsistent operating procedures across shifts, inefficient communication between crews, absence of management during shift business hours (Penkala, 1997), harmful health conditions, high personnel turnover, absenteeism, resentment, poor job performance, and unfit mental and physical conditions that translate to a loss of productivity, quality, and safety (Hung, 1992).

The biggest impacts on shift workers are the sleeping shortages and the difficulties in adjusting the "body rhythm" to a new cycle. Studies indicate that the adjustment in body rhythm to a new work/sleep cycle can require either 7 to 12 days (Costa 1996), or 24 to 30 days (Fly 1980). Humans are designed to work during the day and sleep at night. Therefore, working incongruously with this natural preference affects both an individual's health and job performance. Research shows that night-shift workers usually get about a half-an-hour less sleep than permanent day-shift workers (Kroemer et al. 1997, Shipley 1980). Working shifts intermittently changes a laborer's internal work cycle and time of sleep, affecting important mental processes such as motivation, alertness, and judgment. The result of this interference is lost productivity (Fly, 1980). Safety may also be negatively impacted during the second shift because of increased fatigue, a reduction of support groups, and the potential of poor lighting conditions when working at night (Hanna, 2003). Costa (1996) indicated that shift workers produce more errors and more accidents and may have difficulties in maintaining the proper relationships with family and friends (Costa 1996). Clearly, shift work impacts labor productivity and sheet metal contractors will benefit from the development of an equation to quantify the impact.

Quantifying the Impact of Shift Work on Labor Productivity

To determine the impact of shift work on sheet metal contractors' labor productivity, % shift work was considered. The level of shift work utilized on a project is measured by using % shift work. Percent shift work (% shift work) is defined as total shift work manhours divided by the original budgeted labor hours for the project (Equation 8).

$$\%Shift\ Work = \frac{Total\ Shift\ Work\ Manhours}{Estimated\ Total\ Manhours}$$

Equation: 8

The greater the value of %Shift Work; the more shift work was used. Like overtime, measuring shift work as a percentage of total budgeted manhours allows for a straightforward determination of the effects of shift work on labor efficiency, instead of measuring loss of labor productivity in terms of weeks or months like many typical labor productivity models. The collected research data possessed % shift work limits of 0.02 and 0.53.

$$\text{Productivity Loss} = 0.187 + 0.0676 \ \text{Ln} \ (\%\text{Shift Work})$$

Equation: 9

Linear regression analysis was performed to develop a quantitative relationship between lost productivity and shift work. The model that predicts productivity loss caused by shift work is given as Equation 9. Furthermore, Figure 4 graphically represents Equation 9.

Project size: 3,000 manhours to 550,000 manhours
% Shift Work: 2% to 53%

The shift work Equation is valid for projects only within the ranges of data used to formulate the model. The applicable ranges are:

For projects that fall outside of the ranges of either project size or % shift work, the shift work Equation is not applicable.

An Example Application

To illustrate the shift work Equation, an analysis of project data supplied by a sheet metal contractor from Oregon will be examined. The contractor's scope of work on the project was to fabricate and install an HVAC system for a particular facility. A portion of the work was executed on an existing operating unit. The budgeted manhours for the project were 28,938 hours, and the actual manhours expended at the conclusion of the job were 56,822. The project lasted 35 weeks, including a nine-week time-extension due to a large amount of

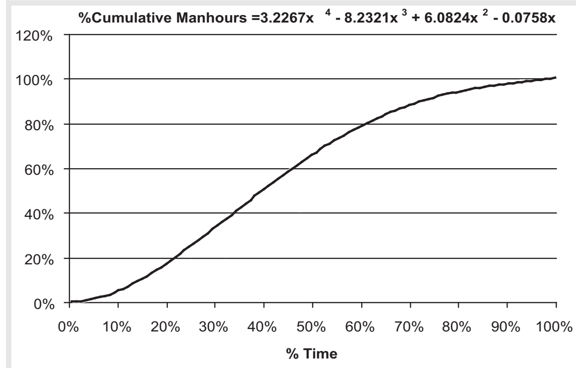

Figure 4: Effects of Shift Work on Labor productivity

changes during construction. However, sufficient time was not granted for the increased scope of work, so the contractor implemented overmanning, overtime, and shift work. The total number of shift work hours was 5,895, representing 20.37% of the total budgeted manhours. This quantity was arrived at by dividing the total number of shift hours by the budgeted hours. Inserting the value of 0.2037 for % shift work into Equation 9, a productivity loss of 0.08, or 8% is calculated. This percentage loss is only pertinent to the total number of hours worked while a second shift was being used. Applying the percentage to the 11,790 total hours worked during the use of shifts (5,895 hours by the first shift and 5,895 hours by the second shift) gives a productivity loss of 943 manhours (11,790_0.08=943) due to the shift work. Therefore, the sheet metal contractor's Delta included a labor productivity loss of 943 manhours as a result of using shift work. The remainder of the loss of manhours over the course of the project can be attributed to overmanning, overtime, possible poor management by the contractor, or a low estimate in the original bid.

Summary

The research reveals that sheet metal contractors experience measurable amounts of productivity loss when overtime, overmanning, or shift work are used to compress the schedule. Sheet metal contractors have benefited in the past from extensive productivity studies on overtime, and limited amounts of research on both overmanning and shift work. As a result of this research, sheet metal contractors can now measure the productivity losses resulting from each schedule compression method. However, it is important to remember that when applying any equation to acquire accurate results, one must operate within the limits of the parameters used when developing the equation. Each productivity equation developed in this study comes with its own limitations and should only be used when all data fits within the bounds thereby set. Ideally, schedule compression would have no impact on labor productivity. Unfortunately, this is not the reality. Therefore, this research has established a means by which the sheet metal industry can measure productivity losses from schedule compression. For the convenience of the contractor, tables of productivity multipliers for each of the three developed equations are provided in the appendix. By definition, a productivity multiplier is simply the difference between productivity loss as a decimal and one. A productivity multiplier of one indicates that no productivity loss has occurred. However, when a productivity multiplier is less than one; loss has occurred. To further aid the contractor, following in the next sections of this summary are "Recommendations for Contractors" It is the intention of the author that this section will be used as a guide to mitigate impacts from schedule compression, or avoid them altogether.

4 RECOMMENDATIONS FOR CONTRACTORS

Introduction

Interaction with industry professionals during the data collection, analysis of case projects, and development of the quantification models revealed certain practices that can be used to both reduce productivity losses and improve the performance of labor during schedule compression. The recommendations provided in this section may either keep a project from being impacted by schedule compression all together, or mitigate the impact of schedule compression on labor productivity when applicable. Following these recommendations will help to encourage an increase in both project and company profitability.

Selection of Schedule Compression Methods

Among overtime, overmanning, and shift work, no option is always superior to the other two methods of schedule compression. However, there are some criteria that can determine the schedule compression method that would best fit the project situation. These criteria include the availability of good supervision, work force, contract terms, site conditions, length of acceleration, etc. For example, if there is not enough supervision or work force, overtime may be the best option. Furthermore, if a contract specifies overtime premium and shift differential, overtime and shift work may be the better choice, instead of overmanning. Additionally, if a site space will not accommodate additional crews, shift work or overtime work would again be used in order to avoid a congestion problem. If there are a limited number of qualified and motivated craftsmen available, use overtime. However, if craftsmen experienced and effective with shift work are available, this method should be used. Lastly, if long-term acceleration is anticipated, hiring more workers (potential overmanning) or doing multiple shift work may be preferable options.

Best Practices and Appropriate Use of Scheduling Compression Techniques

Pre-Construction Planning: Time constraints, material, equipment, and labor availability should be identified during pre-construction planning to adequately establish a realistic project schedule and manpower consumption. These precautions will help to avoid unplanned schedule compression and manpower shortage during the project. Furthermore, it is recommended to establish strong communication with all parties involved in the project, and to encourage their involvement at early stages of the project execution plan.

Project Schedule Management: Develop a realistic schedule, including anticipated weather delays, early in the project and update regularly. Provide a certain period of time as a "buffer" to absorb unanticipated delay events (weather, etc.) for each key milestone. As the project progresses, do more detailed planning by using short-interval scheduling such as 3 weeks schedule.

Project Progress Tracking: Monitor progress daily or weekly instead of biweekly or monthly. Issue status reports regularly, and improve communication with other contractors, construction manager, and owner.

Manpower Management: Record Manpower data, and monitor productivity and absenteeism for detrimental trends. Develop efficiency at recognizing the effect of inefficient labor.

Awareness of Availability of Adequately-Skilled Labor: Hastily seeking more workers may introduce less productive workers. Consequently, the quality of the work may suffer. To ensure adequately skilled workers are available, and to avoid manpower shortages during the project, reappraise labor requirements as the project goes on, and assess company or local manpower availability from time to time.

Be Selective on the Work Assigned to a Second Shift: By assigning completely different tasks to the second or third shift, shift operations are greatly improved. These tasks should be totally independent from the tasks performed by the previous shift, including different materials and tools. In addition, it is recommended that a second shift be used only for a well-defined and relatively small scope of work that requires minimal engineering and design support, due to the difficulties in managing a shift schedule and the limited off site support. A smaller scope will facilitate coordination, planning, and supervision of the second shift. Material requirements should be minimal, since most supply stores are closed during the working hours of second and third shifts.

Overlapping Management: Overlapping of supervision is needed to ensure smooth hand-overs between shift groups. This overlap helps to avoid low productivity and rework between shifts, and to improve coordination by letting workers know what has been completed by the previous crews. This can be accomplished by requiring the foreman of the first shift to stay 1-2 hours longer, and the foreman of the second shift to arrive 1-2 hours earlier.

Innovative Crew Scheduling: Using innovative crew scheduling such as four ten hour days can be very useful, since variable shift arrangements can increase production and improve productivity. However, special arrangements generally are not effective in short-term accelerations; and therefore, should be implemented only in long term acceleration situations.

Keep the Shift Schedule Regular and Predictable: Workers should know their schedule well ahead of time, so they can plan their rest, child care, recreation, and contact with family and friends. This will help the workers keep upbeat attitudes. Furthermore, irregular schedules contribute to accidents by producing fatigue from sleep loss.

Small Overtime Durations: Short durations of overtime have a reduced effect on productivity in comparison to extended overtime usage. If used for short, intermittent durations, overtime efficiency loss can be curtailed. Therefore, utilize spot overtime rather than extended duration overtime on crafts or tasks on the critical path.

Enough Supervision: As crew size increases, the subsequent dilution of supervision may result in a poor quality of work. Add more foremen and supervisors as the work force is increased to provide timely answers to engineering questions and request for clarification.

Managerial Support: Working overtime or implementing multiple shift work eliminates some of a worker's time with his family and time for social relationships. An overtime premium and shift differential does not always compensate for this loss. Additional compensation should be given to workers to increase efficiency and company relations.

Avoid Congestion: When adding more crews is necessary, add more crews only within the work space allowed. Since available working space in a construction site changes day to day, the project manager should keep his eyes on the net work space on site. When the site is very congested, shift work can be most effective.

Avoid Material, Tool, and Equipment Shortage: As the crew size increases and overtime workhours increase, corresponding material, tools, and equipment should be provided with the same rate of increase. Assigning a material control coordinator to the project and increasing the inventory of spare parts, hand tools, and expendables may reduce material, tool, and equipment shortage.

Minimize Workhours on Site by Using Modular and Pre-assembled Components: When large number of components can be pre-assembled, it is a good idea to do as much work as possible in the shop, rather than in the field. As a result, productivity is enhanced by eliminating "assembling" inference by other trades, weather problems, and job-site congestion.

Sufficient Amount of Artificial Lighting: When working under a second shift schedule, safety will be greatly improved by providing a sufficient amount of artificial lighting.

5 CONCEPT FILE FOR TRADITIONAL SCHEDULE COMPRESSION TECHNIQUES

PREFACE

Sheet Metal contractors confronted with the need to compress a construction schedule face the potential for extreme difficulties. Unfortunately, a limited knowledge base exists for determining the techniques, methods, and concepts to be employed to mitigate these potential negative outcomes. One of the more difficult problems associated with schedule compression is the associated delays, disruptions, and partial work suspensions that are commonly concurrent. In the most severe situations, a compressed contract schedule completed using inappropriate methodologies can ruin the financial health of an electrical contractor.

This part of the report presents a collection of "concepts" that can be effectively employed in planned compressed schedule situations to mitigate the potential negative effects of overtime, overmanning and second shift. Each concept begins with a description of the foundation and details of application, and is followed by information on when to apply, conditions for successful application, cautions, cost implications, and illustrations and example. It is important that the sheet metal contractor consider the specific conditions of the schedule compression and the project, along with the information presented in this document, before selecting an appropriate concept to employ. Numerous project factors can be significant and critical to the outcome of the implementation of each concept.

PLACE THE CREW ON OVERTIME

Description:

This concept involves employing the existing crew members beyond the standard 40 hours per week. This typically includes the extension of the eight hour day to a 9-12 hour day, the extension of the five day work week to 6-7 day work week, or a combination of both.

Additional Details:

Numerous research reports show that labor productivity declines with the extended use of overtime.

When to Apply:

Can be effective in short interval schedule compression. Used when electricians are not available for crew size increases or the creation of a second shift.

Conditions For Successful Application:

1. May want to expend the extra dollars for overtime to maintain good client relations.

2. Excellent when crew members are not needing to go home (see example below).

3. Advanced planning reduces the impacts of overtime including advanced tooling and planning of material layout and storage areas.

4. Give employees extended weekend breaks on occasion to "recharge" the crew productivity, especially during long durations of overtime.

Cautions:

- Employee burnout, personnel inefficiencies, and lost time during the work week for personal activities normally accomplished during overtime hours are factors which reduce the efficacy of this approach over the long term.
- Some crew members will purposely reduce productivity to maximize overtime income.

Cost Implications:

- Pay at 1 1/2 times the normal hourly rate plus other union requirements can make the effective hourly labor rates double.
- Maintain certified payroll for cost reimbursement.
- In most cases, two premiums are paid for scheduled overtime. The first is increased wages and the second is less productivity per manhour worked.

Illustration and Examples:

Many times, especially in very large projects, workers and other crew members stay at or near the project site and away from home during the week. Since the workers have to stay near the site, distractions away from work are minimized. Workers tend to want overtime for the extra income. This willingness to work overtime reduces the lost productivity effect of overtime hours.

On large projects, communication is critical to maximizing the productivity during long durations of overtime. On one project, the contractor conducted 1 hour nightly meetings with all foreman to coordinate efforts. This contractor also formed a five person TQM team that meet once a week for an hour to maximize the productivity of the many project activities. This contractor also hired a productivity expert to work with them in developing material and tool storage areas and other planning efforts to maintain productivity. All of these items helped stabilize productivity levels in extended overtime situations.

In short duration schedule compression, contractors report that the additional costs associated with placing crews on overtime may be less than the costs of the lost time associated with training, orientating, and socializing new workers.

ADD ADDITIONAL MANPOWER TO THE PROJECT

Description:

This concept involves the addition of staff to existing crews. Thus, a 5 person crew may be increased to an 8, 10, or more person crew. May also involve the creation of new crews. No changes in the scheduled work hours are implemented.

Additional Details:

Requires the availability of qualified workers. Some studies have shown that overmanning may be the best solution to schedule compression because less inefficiencies are incurred. However, each project has a saturation point were additional manpower provides no significant benefit.

Requires an increased awareness of safety issues and increased availability of accessible water, eating areas, people lifts, first aid stations, restrooms, etc. to accommodate the additional workers.

When to Apply:

When additional manpower does not lead to over congestion and the type of work conducted leads itself to positive benefits with overmanning.

On long-term planned schedule compression situations and when the training and orientation costs of adding additional workers is less than placing the current workers on scheduled overtime.

Conditions For Successful Application:

1. Assign the extra personnel to non-critical project tasks.

2. Maintain normal crew levels and assignments on critical path items.

3. Ample work area must be present without congestion.

4. Equipment and material delivery must be able to meet the needs of the additional manpower.

5. Must have additional supervision available.

6. Must have little involvement with other trades (if project is trade congested, no advantage to overman).

7. The type of work must be suited for overmanning.

8. Contractor must have scheduling ability to maintain control of the work.

9. There must be an adequate labor supply available with relevant construction experience.

Cautions:

- Lost productivity due to learning curve applications, training, orientations, start-up, and socialization must be evaluated.
- Must evaluated how well each crew member gets along with the other crew members, the equipment and materials required by the additional crew members, and the available space and task separation to avoid interruptions and work overlap. Research has shown that each of these leads to reduced productivity.
- Insufficient work area size can lead to negative results.
- Overmanning can "eat up" hours when workers are forced to wait for others and management is spread to thin to monitor each and every activity.
- May not be appropriate if equipment delivery requirements are critical.
- Difficult to manage speed of material flow.
- In some cases, an increase in crew size will provide a disproportional level of duration reduction, resulting in an incremental cost which must be considered.
- Certain situations will exist in which an increase in crew size will actually result in an increase in task execution time.
- Space congestion and overcrowding will provide detrimental effects to overmanning.

Cost Implications:

- Can maintain 40 hour weeks and avoid overtime premium pay.
- Labor productivity tends to decrease as the percent overmanned increases.
- Have additional costs for tools, equipment, and increased supervision.
- Productivity can be lost because of stacking of trades, lost moral, too many people on the job, and fatigue.

- Requires a larger ratio of supervisors and a lesser ratio of apprentices to electricians thus crew labor costs increase.
- When additional manpower is brought in from outside of the local area, contractors have reported that the overall productivity tends to decrease.
- The administrative and labor costs associated with training new workers, orientations on project procedures and safety policies, and getting to know the new crew members may be significant. Other concepts may prove to be more cost effective.

Illustration and Examples:

Additional manpower assigned to the more medial tasks that require little explanation reduces the learning curve to negligible levels and frees up the more qualified staff for productive work.

It is the experience of this writer that overmanning should be the least desirable option for schedule compression.

ADD A SECOND SHIFT

Description:

This concept involves the use of a second crew on a project. Each crew generally works an 8 hour shift.

Additional Details:

Will require supervision overlap for continuity between shifts. Will require additional tools and separate gang boxes for each crew.

When to Apply:

Effective when rented or high cost equipment is necessary for production. Effective for longer duration schedule compressions. Desirable when work area is extremely congested during normal hours. Also desirable in the most severe schedule compressed situations.

Conditions For Successful Application:

1. Must overlap management of the project so that crews are aware of what has been completed by the previous crew. This is especially important if crews are to be involved in similar or related work tasks in the same area.
2. This concept is best when sperate work tasks are available for each crew.
3. Qualified workers must be available to form a second crew.
4. Project must be large enough to support a second shift (difficult on small projects).
5. Successful when the owner is willing to allow two crews and extended hours on the project.
6. Successful when material requirements are minimal and available for both shifts.
7. Must keep first and second shift material deliveries separate.
8. Best when separate work tasks are available for each crew.
9. Successful when contractor has additional tools and equipment available to support shifts.
10. Contractor must have scheduling ability to maintain control of the work.
11. Must have all the project information you need so that decisions can be made when project management is not on-site.

Cautions:

- Must know the length of the required schedule compression. Not effective on very short durations.
- Start up and learning curve issues reduce the initial productivity of each crew.
- Resource management becomes more critical.
- Overall project management becomes difficult and requires an exceptional manager.
- May not be desirable if security of the project is a problem.
- May not be appropriate if tedious control is required to maintain the project.
- Materials will have to be delivered earlier and more often and may require additional storage space.
- If specialized task, training time must be included in schedule and cost.
- Continuity of work is lost which leads to productivity decreases.
- To avoid rework, crews must complete 100% of the task work prior to turning the work over to a second crew.
- May not be feasible on mega projects.
- There is a considerable body of literature suggesting that shiftwork in general, and second shift work in particular, may have adverse consequences for the health and well-being of the worker.

Cost Implications:

- Shift work may have the lowest cost impact to both the contractor and the customer.
- Well managed second shifts can yield negligible losses in labor productivity.
- Crews tend to become very equal in the long run.
- Owners usually willing to accept shift work because they avoid the expense of premium pay for overtime.
- Will require foreman to work premium hours to "rollover" responsibility between shifts. Thus, additional management costs.
- Shift work will increase overhead cost because support staff will have to be increased.
- Although the crews are not working overtime, office support staff, material delivery staff, and management will be required to work additional hours to keep up with the needs of the crews.

Illustration and Examples:

On very large projects where the schedule is compressed, a second shift is not possible. One contractor reported that they had a project where the original estimate called for 80 workers. With changes and many revised contracts, he actually had up to 750 workers on the project. Because of the enormous crew sizes, there wasn't enough management talent available to develop two management teams for two shifts. Also administration and material support was not sufficient to support two shifts. Thus, using two shifts was not possible on this project.

6 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, order materials and equipment, erect support facilities, and recruit and mobilize a labor force. 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 paramount in the construction industry, especially for labor-intensive specialty contractors such as the electrical, mechanical, and sheet metal trades. These labor-intensive trades typically consume between 33% and 55% of the total project budget in labor cost, which is the most variable and riskiest project budget component. Having tools to manage the workforce 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 5 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 5, 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 5, 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.

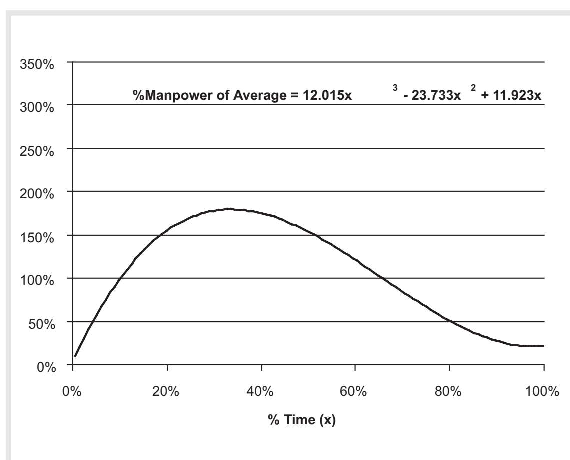

Figure 5: %Manpower of Average Curve

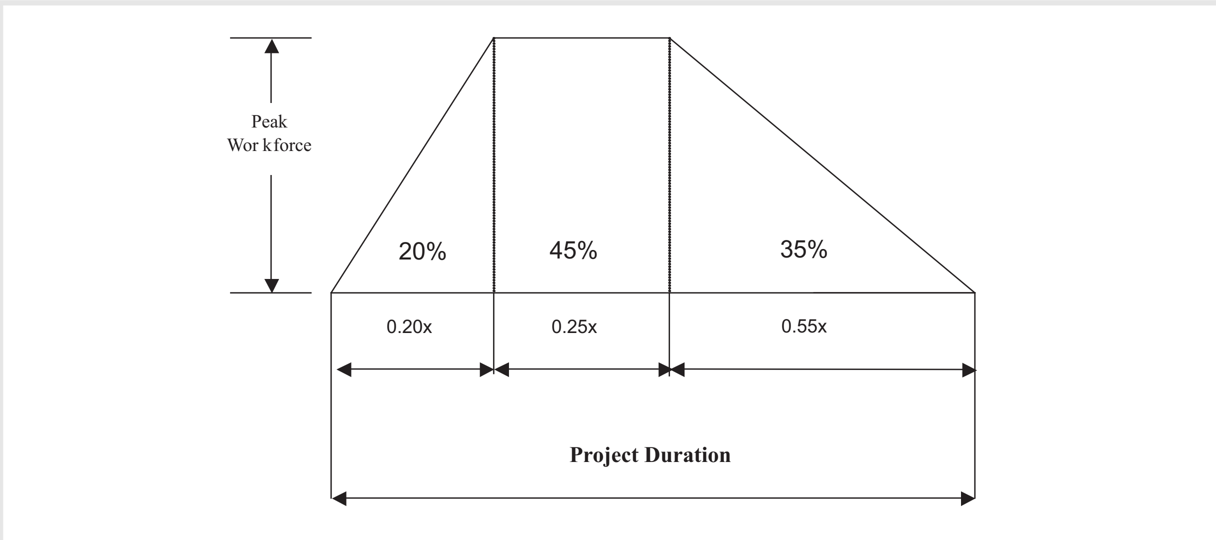

Figure 6: Trapezoidal Approximation of Sheet Metal Manpower Loading

To facilitate an easier, more accessible figure for use by contractors in the field, a trapezoidal approximation to the curve developed in Figures 5 is given below in Figure 6. 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.
6. The remaining 35% of the project manpower is consumed across the final 55% of the project duration. This is the project manpower rundown.

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 Curves or Progress Measurement Curves, 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 are also constantly used in scheduling and planning for reporting actual, earned, and planned values and for resource loading various activities of a project.

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:

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 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

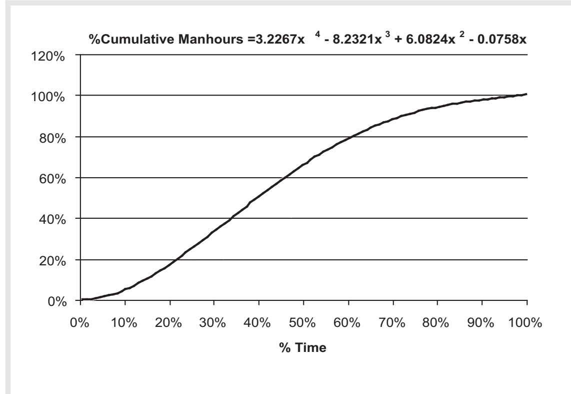

Figure 7: Sheet Metal Industry S-curve

cumulative manhours on the y-axis. The developed curve is shown in Figure 7. 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 duration inserted as a decimal (0.0 to 1.00).

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.

7 CONCLUSIONS

The prime objective of this study was to investigate and quantify the labor productivity impacts on sheet metal contractors from the utilization of the three most common schedule compression methods: overtime, overmanning, and shift work. The objective was achieved by developing quantification models for each respective method by using linear regression on the collected data.

Unfortunately, schedule compression is a common problem in the construction industry. Its implementation negatively impacts labor productivity and subsequently, it often becomes a source of disputes. Therefore, understanding how and how much schedule compression affects labor productivity, and which schedule compression method will be the most labor-efficient and cost-effective, is crucial for increasing project performance and maintaining sound financial status of one's company.

Unfortunately, numerous court cases reveal that contractors usually fail to provide sufficient evidence to prove a productivity loss. By using the models developed through this research, sheet metal contractors now have an effective way to prove their loss. The study team recommends that the owner and contractor agree to utilize the developed models for schedule compression dispute resolution prior to signing the contract. Additionally, the study team recommends that the sheet metal contractor follow the recommendations provided in order to mitigate productivity loss from schedule compression.

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9 APPENDIX I: GLOSSARY

Delta

The difference between the actual total manhours consumed to complete a project and the estimated base hours (including the approved change order hours).

Delta Approach

The macro concept by which Delta was developed.

Factors Approach

The concept where the cumulative impact of various factors on labor productivity equate to the actual total manhours beyond the budgeted level (plus approved change order hours) expended to complete the project. In other words, each factor contributes to a portion of the total productivity loss (Delta).

Labor Productivity

Unit or dollar of output per labor hour of input.

Learning Curve Effect

The effect on a worker that increases the production rate of a task when that worker continues to perform the task repetitively.

Linear Regression

A method of modeling that determines the relationship between one or multiple independent factors and a single dependent factor. Throughout this study, a single dependent factor is %Delta (Productivity loss) and the independent factors are %Overtime, %Shift work, and Peak over average ratio.

Overmanning

1. Putting additional workers on a job in excess of the optimal crew size.

2. Increasing the ratio of peak number of workers of the same trade over average number of workers during project to a value greater than 1.6.

Overtime

Workhours in excess of 40 hours per week, or working more than 8 hours per day or more than 5 days per week.

Peak Over Average Ratio

The ratio of the actual peak number of workers over the actual average number of workers for a particular trade. A ratio greater than 1.6 indicates the presence of overmanning.

Percent Shift Work (%Shift Work)

The total shift work manhours divided by the original budgeted labor hours for the project.

Percent Overtime (%Overtime)

The total overtime manhours worked on a project divided by the estimated total manhours.

Productivity Multiplier

The relative productivity under specific schedule compression methods when the productivity of a standard workhour is equal to one.

Schedule Compression

A reduction from the normal experienced time or optimal time typical for the type and size of project being planned within a given set of circumstance.

Percent Delta (% Delta)

$$\% \, Delta = \frac{Actual\,Total\,Manhours - (Estimated\;Total\;Manhours + Approved\,Change\;Order\,hours)}{Actual\;Total\,Man\,hours}$$

Schedule Compression Method

A method used to accomplish the work in the lesser time when the schedule is compressed

Shift Work

The hours worked by a separate group of workers whose work on a project begins after the first workforce of the same trade has retired for the day.

10 APPENDIX II: PRODUCTIVITY MULTIPLIERS

A. Productivity Multipliers for Overtime

%Overtime	Productivity Multiplier
6%	0.911
8%	0.905
10%	0.898
12%	0.891
14%	0.884
16%	0.877
18%	0.870
20%	0.863
22%	0.857
24%	0.850
26%	0.843
28%	0.836
30%	0.829
32%	0.822
34%	0.815
36%	0.809
38%	0.802
40%	0.795
42%	0.788
44%	0.781
46%	0.774
48%	0.768
50%	0.761

B. Productivity Multipliers for Overmanning

Peak over Average Ratio	Number of Workers of a Trade				
	10	20	30	40	50
	Productivity Multiplier				
1.7	0.945	0.896	0.867	0.847	0.831
1.8	0.933	0.884	0.855	0.835	0.819
1.9	0.922	0.873	0.844	0.823	0.808
2.0	0.910	0.861	0.832	0.812	0.796
2.1	0.898	0.849	0.821	0.800	0.784
2.2	0.887	0.838	0.809	00.789	0.773
2.3	0.875	0.826	0.797	0.777	0.761
2.4	0.864	0.815	0.786	0.765	0.750
2.5	0.852	0.803	0.774	0.754	0.738
2.6	0.840	0.791	0.763	0.742	0.726
2.7	0.829	0.780	0.751	0.731	0.715
2.8	0.817	0.768	0.739	0.719	0.703
2.9	0.806	0.757	0.728	0.707	0.692
3.0	0.794	0.745	0.716	0.696	0.680
3.1	0.782	0.733	0.705	0.684	0.668
3.2	0.771	0.722	0.693	0.673	0.657
3.3	0.759	0.710	0.681	0.661	0.645
3.4	0.748	0.699	0.670	0.649	0.634
3.5	0.736	0.687	0.658	0.638	0.622
3.6	0.724	0.675	0.647	0.626	0.610
3.7	0.713	0.664	0.635	0.615	0.599
3.8	0.701	0.652	0.623	0.603	0.587

C. Productivity Multipliers for Shift Work

%Shift Work	Productivity Multiplier
2%	1.077
4%	1.031
6%	1.003
8%	0.984
10%	0.969
12%	0.956
14%	0.946
16%	0.937
18%	0.929
20%	0.922
22%	0.915
24%	0.909
26%	0.904
28%	0.899
30%	0.894
32%	0.890
34%	0.886
36%	0.882
38%	0.878
40%	0.875
42%	0.872
44%	0.868
46%	0.865
48%	0.863
50%	0.860
52%	0.857

11 ABOUT THE AUTHOR

Awad S. Hanna is a professor and chair of construction engineering and management program at the University of Wisconsin-Madison, department of Civil and Environmental Engineering. Dr. Hanna holds M.S. and Ph.D. degrees from Penn State University and he is a register professional egineer in the US and Canada. Awad has been an active construction practitioner, educator and researcher for over 25 years. Awad was a project manager and a design engineer for 10 years. He has taught construction management courses at Penn State University, Memorial University of Newfoundland, Canada, and University of Wisconsin-Madison. Dr. Hanna has conducted several research projects for the New Horizons Foundation including landmark studies on the cumulative impact of change orders on sheet metal contractors' labor productivity, schedule compression, and acceleration, and pre-construction planning. Dr. has conducted research for other national organizations including the Electrical Contracting Foundation, Mechanical Contracting Foundation, Construction Users Roundtable (CURT) and the Construction industry Institute. Dr. Hanna has taught for than 300 successful seminars and workshops in more than 35 states on topics such as change orders impacts, project scheduling, earned value analysis, labor productivity, and construction delay claims.

Dr. Hanna is also a national consultant representing many contractors to recover productivity losses related to change orders, acceleration and compression, delay, and trade stacking.