On-Site Manpower Increasing Impact on Labor Productivity

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요 약

During a typical construction project, a contractor may often 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 to compensate for the reduction in available time. The most frequent initial reaction of contractors to this situation is to increase on-site manpower by working longer time (overtime), adding more workers (overmanning), or implementing shift work (shift work) to increase the rate of progress. The goals of this study were to investigate how these three methods affect labor productivity and to quantify their impact on labor productivity by analyzing real project data collected from sheet metal contractors and mechanical contractors in the US.

키워드: Schedule acceleration, Manpower, Overtime, Overmanning, Shift work, Labor productivity

1. Introduction

Time conservation is a prime concern for both owner and 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 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 requires the contractor to complete a project in a less than normal time frame originally needed or requires 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.

When it is necessary to speed the work up, contractors have to make a decision in selecting a method that accelerates the schedule while minimizing the cost impact to the project. There are a number of methods of doing this. The work may be accelerated by focusing on the activities on 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, the most frequent initial reaction of contractors to schedule acceleration is to increase on-site labor force. Several studies indicate that the most common way of increasing on-site labor force includes either to work longer hours, to add more labors, or to implement multiple shift instead of single shift (Noyce and Hanna 1998, Horner and Talhouni 1995, CII 1990,). The contractor may implement one of these or combination of these.

At first examination it may seem that on-site manpower increasing would be an effective solution for

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construction problems associated with time. Unfortunately, it 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 the largest percentage of total costs. Therefore, understanding how and why these three methods affect labor productivity is essential for successful claims avoidance. In this way, the owner and contractor will be adequately informed on how these three methods affect labor productivity, and furthermore, the owner will realize that this impact comes with a cost.

The objectives of this study were

· To investigate why and how overtime, overmanning, and shift work impact labor productivity

· To quantify the effect of overtime, overmanning, and shift work on labor productivity

2. Research Methodology

2.1 Factors Approach

Understanding the effects of overtime, shift work, and overmanning on labor productivity is quite difficult because the factors affecting labor productivity in the schedule acceleration situation are numerous. In a situation of schedule acceleration, a number of factors such as overtime, shift work, overmanning, and stacking of trades affect labor productivity. The cumulative impact of these factors on the productivity of labor equate to the actual total manhour beyond the budgeted level expended to complete the project. Waldron (1968) introduced factors approach in which the researcher could theorize each of the factors contributing to a portion of the total productivity loss. This approach has been adopted to determine the impact of overtime, overmanning and shift work on labor productivity.

2.2 Project Level Productivity Measurement

To determine productivity under a macro –analysis, estimated hours are taken as the measure of output and actual hours are taken as the measure of input (Hanna et al. 1999). Lost productivity can be measured by the difference between the actual labor hours expended to complete the project and the estimated base hours (including the approved change order hours). A loss of productivity 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. To be able to compare projects of varying size, it is necessary to normalize productivity as a percentage. Percent Lost Productivity is simply a project's lost productivity divided by actual manhours consumed to complete the project (Hanna et al. 1999). As a mathematical expression, Percent Lost Productivity (% lost productivity) is given in Equation 1, below (Hanna et al. 1999).

%Lost Productivity
= [Actual Total Manhours–(Estimated Total Manhours + Approved Change Order Hours)] ÷ Actual Total Manhours (1)

The strength of this method is its representation of the direct effects, as well as the indirect effects, on productivity since actual labor hours are calculated after the completion of project.

2.3 Data Collection

To see the impact of these three methods on labor productivity, data was collected from geographically diverse specialty mechanical and sheet metal contractors. These two trades are similar because they are both labor intensive and connected trades. Connected trades mean there is a distance between source of energy and its final destination. In addition, according to the Occupational Outlook Handbook (2002) published by the Bureau of Labor Statistics, the majority of sheet metal contractors are working for Heating, Ventilation and Air-conditioning (HVAC), and plumbing in the construction industry ,which represent a main work item for mechanical contractors too. Six different types of construction performed in 28 states are represented. The project sizes in terms of manhour range from 700 to 208,451 total manhours.

A questionnaire was used in the acquisition of data for this study and consisted of two parts: (a) information on the contractors' background and (b) information describing a specific project that experienced overtime, overmanning, or shift work due to schedule acceleration. Questionnaires were distributed to mechanical contractors and sheet metal contractors in the U.S. with telephone and e-mail follow-up. In some cases, author visited contractors to have better understanding of the project utilized in this study. A variety of project factors were collected: project type, size, type of owner, project delivery method, contractor's role, type of contract, contractor's project management practice, productivity information, and project schedule along with estimated and actual manpower loading graphs.

3. On-site Manpower Increasing Impact on Labor Productivity

As mentioned in previous section, the most frequent initial reaction of contractors to schedule acceleration is to increase on-site manpower by working longer hours, adding more workers, implement multiple shift , or combination of these. Thus, this study will focus on why and how these three methods affect construction labor productivity and how much they impact labor productivity.

3.1 Overtime

Overtime is defined as workhours in excess of 40 hours per week. 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 1998). Overtime is not only used for schedule acceleration, but is often used for other purposes. For example, overtime may be scheduled in order to maximize equipment use, to take advantage of good weather, to avoid penalties for late completion, or to 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.

3.1.1 Effect of Overtime on Labor productivity

Premium pay, the amount paid in excess of straight time pay, is the most obvious of the increased costs. But the cost of overtime cannot be fully explained only by the premium pay, because there are additional manhours caused by lost productivity during the implementation of overtime that must be paid for. The two adverse effects (premium cost on overtime hours and reduced productivity) combine so that each productive hour gained costs, on average, 300% of the straight time hourly rate (Smith 1987).

Understanding the effects of overtime work on labor productivity is quite difficult because the factors affecting labor productivity in an overtime situation are numerous. But, there are certain common factors that affect labor productivity regardless of background.

The most prominent factors that negatively affect labor productivity during overtime are physical and mental fatigue. The worker will experience some degree of physical and mental fatigue brought on by the longer working hours. Furthermore, McGlaun (1972) and Smith (1975) indicate that workers may perform less productively in order to obtain overtime work. For example, a contractor may be asked to expedite only a portion of the work. As a result, only the workmen working on that portion will work overtime, and the other workers on site may reduce their production rates in order to work overtime as well. Furthermore, once overtime becomes unnecessary, the contractor will want to go back to normal working hours. Subsequently, workers may perceive the project as a low earnings site and look for another job that has overtime.

Moreover, overtime will probably cause an increase in absenteeism. Smith (1985) explained the reason for the increase in absenteeism from the physical aspect, while

McGlaun (1972) examined the mental and social aspects. A reduction in the economic concern of workers, the additional fatigue reaction of individuals, and various combinations of these factors will increase absenteeism (McGlaun 1972). Other effects of overtime are increased injury and accidents, reduced supervision and effectiveness, and increased error and omission due to physical and mental fatigue (Kossoris 1947, Howerton 1969). Also, the quality of work may suffer (Smith 1987), and overtime jobs are apparently more susceptible to jurisdictional disputes.

3.1.2 Quantifying the Effect of Overtime on Labor Productivity

Unlike scheduled (or planned) overtime, there has been no firm equation to estimate the impact of unscheduled overtime on labor productivity which occur irregularly, say 4 hours in first week, 9 hours in week2, and so on. For the purpose of quantifying of the effects of unscheduled overtime on labor productivity in 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.

$$\%\,Overtime = \frac{Total\ Overtime\ Manhours}{Estimated\ Total\ Manhours} \quad (2)$$

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 productivity, 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 analyzing 39 projects which experienced overtime during project implementation by which a productivity loss due to overtime can be predicted The R2 value of the regression is 30.9%. Considering the type of data analyzed, the value for R2 is acceptable. The p-value of the regression analysis was 0.000, and p-values for predictor were also statistically significant with value of 0.0019.

$$\%\ \text{Productivity Loss due to overtime} = 0.06804 + 0.34257 \times \%\ \text{Overtime} \quad (3)$$

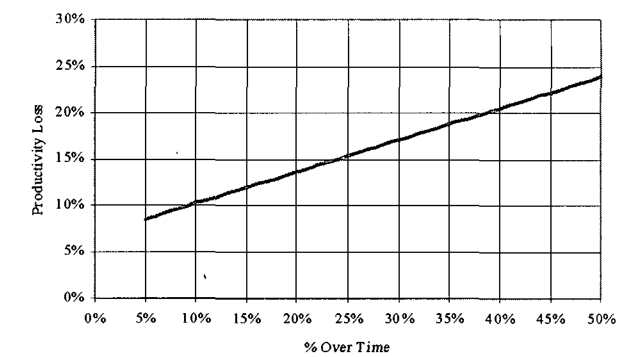

Figure 1. Effect of Overtime on Labor Productivity

Equation 3 allows mechanical and sheet metal contractor to calculate their productivity loss by simply inputting % Overtime experienced on the project of interest. If % Overtime is less than 5%, study results indicate that the amount of overtime is not significant enough to impact productivity. 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.

3.1.3 Example Application

This section validates, and explains the use of the overtime model by analyzing project data supplied by a contractor from Minnesota. The project was commercial in nature and experienced schedule acceleration as a result of delays by the general contractor. The specialty subcontractor implemented overtime to complete the project as originally scheduled. The project consisted of 8,811 total actual manhours worked, with an original estimate of 7,340 manhours; a loss of 1,471 manhours. The project record shows that rigorous overtime was used on the project, primarily between week 12 and week 23. During this period, the total manhours expended was 5,892 hours, and the total overtime manhours expended was 1,259.5. Thus,

$$\% \text{ overtime} = 1,259.5 \div 7,340 = 0.172 \text{ (or } 17.2\%) \quad (4)$$

Inserting the % overtime of 17.2% (0.172) into Equation 3 gives a productivity loss of 0.127, or 12.7%.

% Productivity Loss due to overtime

$$= 0.06804+0.34257 \times 0.172 = 0.127 \text{ (Or } 12.7\%) \quad (5)$$

Multiplying 0.127 by the total actual manhours used during week 12 to 23 (5,892) gives a loss of 748 manhours due to overtime

Lost manhour due to overtime

$$= 0.127 \times 5,892 = 748 \text{ manhours} \quad (6)$$

As a result of the 1,471 manhours that were lost during construction, 748 manhours can be estimated as attributed to inefficiencies caused by overtime. The remainder of the hours lost, 723 manhours, would be due to other factors, such as the contractor's inefficiencies, stacking of trades, or poor field management.

3.2 Overmanning

Overmanning can be defined in two different ways. First, overmanning is 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 certain ratio.*

3.2.1 Effect of Overmanning on Labor productivity

Productivity losses due to overmanning result from a variety of circumstances stemming from schedule acceleration. 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 efficiently until the second or third week (Horner and Talhouni 1995, Smith 1987, Brunies and Emir 2001).

3.2.2 Quantifying the impact of Overmanning on Labor Productivity

To measure the impact of overmanning ,second definition of overmanning was adopted for this study. Different values of the ratio were introduced by several studies; 1.35 for electrical, 1.50 for mechanical (Hanna 2001), and 1.6 for normal civil projects from Allen's study (Wideman 1994). Clark (1985) reported a ratio of 1.54, but failed to mention the type of construction for which the ratio is applicable. For this study, Allen's ratio was selected because it represents the worst-case scenario for overmanning. Consequently, if peak over average ratio is greater than 1.6 then we can say the project experienced overmanning, and if peak over average ratio is equal to or less than 1.6 then the project would be regarded as not having experienced overmanning. Unlike stacking of trades which considers all the workers on site from all trades, overmanning deals with only one trade.

Two variables, Ratio of Actual Peak Manpower over Average Manpower and Actual Manpower at Peak, were selected through stepwise method.

- Act. Peak/Avg = Actual Peak Manpower / Actual Average Manpower
- Log (Act. Peak) = Log of Actual Manpower at Peak (the Number of workers of sheet metal worker (or mechanical worker) at peak)

Multiple regression analysis followed to determine a quantitative relationship between overmanning and productivity loss with putting Percent Lost Productivity as the response variable and two independent variables (Act. Peak/Avg., and Log (Act. Peak)) as predictors. A final regression model was developed and is given as Equation 7.

%Productivity Loss due to overmanning
=−0.305+0.116 x Act. Peak/Avg + 0.163*Log(Act. Peak) (7)

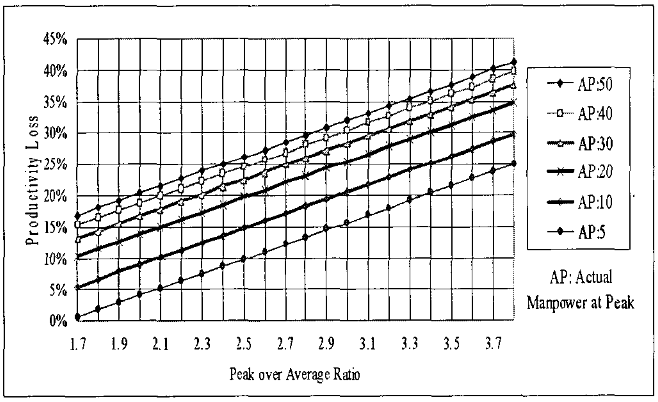

Figure 2. Effect of Overmanning on Labor Productivity

The result shows the R2 value of the regression is 45.5%, a high value for the type of data analyzed. The p-value of the regression analysis was 0.000, and p-values for predictors were 0.000 for both predictor variables also statistically significant, indicating a relatively strong regression model. The sample size was 54. The applicable ranges are:

- Project size: 700 ~ 208,451manhours
- Peak/Average Ratio: 1.70 ~ 3.76
- Actual Manpower of a sheet metal or mechanical contractor at Peak: 4 ~ 50

For projects that fall outside of the ranges for either project size or Peak/Average ratio the model given in Equation 7 is not applicable.

3.2.3 Example application

As an example, an analysis of project data supplied by a sheet metal contractor from St. Louis, Missouri, was examined. The project began in January 2002 and was supposed to be completed May 2003. The sheet metal contractor was asked to complete the mechanical scope of work by the end of January 2003. Since the time available for the contractor to complete its work was significantly reduced, the sheet metal contractor had to add more workers to meet the deadline. The project experienced an actual productivity loss of about 4,600 manhours.

The manpower loading graph of the project shows that severe overmanning was experienced during the period of week 16 to week 50 (almost the entire project). The actual peak manpower was 15 during the 40th week and the actual average manpower over the course of the project was 6.7. The actual peak over average ratio is 2.24, a value greater than 1.60, implying that overmanning was indeed present.

Actual/Average Ratio= 15 ÷ 6.7 = 2.24 (8)

By inserting values into the overmanning model, a productivity loss of 0.1465 (14.65%) was obtained.

% Productivity loss due to overmanning
= − 0.305+0.116 x 2.24+0.163 x Log 15
= 0.1465 (or 14.65%) (9)

This quantity is only applicable to the portion of the project impacted by overmanning, not the entire project, and represents only the lost productivity caused by overmanning. Applying the results of the overmanning model, 14.65% would be multiplied by the portion of the project impacted by overmanning, from week 16 to week 50. A total of 11,694 manhours were spent during these weeks. Multiplying the results of the overmanning model 0.1465, by the 11,694 manhours gives an estimate of 1,713 manhours that can be attributed to overmanning.

Lost manhour due to overmanning
= 0.1465 x 11,694 = 1,713 manhours (10)

The remainder of the hours lost, approximately 2,887 would be due to other factors such as stacking of trades, contractor's inefficiencies, or poor field management.

3.3 Shift work

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. The second shift schedule is very effective at reducing project duration, because it allows the amount of weekly work hours to be approximately doubled. Shift work is sometimes preferred to overmanning and overtime, because it can produce the higher rate of progress necessary without inefficiencies from physical fatigue caused by overtime work and congestion problem associated with overmanning. In addition, premium payment for a second shift is typically lower than that of overtime premium. When a work site is very congested due to overmanning, adding a second shift is a potential solution. However, shift work has also disadvantages and introduces additional cost.

3.3.1 Effect of Shift work on Labor productivity

In general, shift work is less common in construction industry. It is for these reasons that the disadvantages associated with shift work are not addressed and instead are merely accepted as the consequences of utilizing shifts. A large amount of studies have been conducted in other industries, particularly in manufacturing and nursing. Though not from construction, the data used in these studies attempts to relate the effects of shift work on human performance.

The biggest impacts on shift workers are sleeping shortage and difficulty in adjustment in body rhythm into new cycle. Night-shift workers have about half an hour less sleep than permanent day-shift workers. Adjustments in body rhythms to new work-sleep cycle require 7 to 30 days (Costa 1996, Fly 1980). Humans are designed to work during the day and sleep at night. Working in congruously with natural preferences affects both an individual's health and job performance. Fly (1980) concurred with Hung in his assessment that shift work decreases productivity. 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 be negatively impacted during the second shift because of increased fatigue, a reduction of support groups, and potentially 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 social levels (Costa 1996).

Other problems associated with shift work are there is no single point of responsibility for the progress and quality, and sometimes a period of wasteful overlap is necessary for smooth changeover. Penkala (1997) and Hung (1992) reported some of the common problems associated with shift work. The problems are little cooperation between shifts, inconsistent operating procedures across shifts, inefficient communication between crews, and absence of management regular business hours (Penkala, 1997), harmful health conditions, high personnel turnover, absenteeism, resentment, poor job performance and unfit mental and physical conditions-situations that translate to loss of productivity, quality, and even safety (Hung, 1992).

3.3.2 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 estimated labor hours for the project (Equation 11).

$$\% \text{ Shift Work} = \frac{\text{Total Shift Work Manhours}}{\text{Estimated Total Manhours}} \quad (11)$$

The greater the value of % Shift Work the more shift work was used. Like overtime, measuring shift work as a percentage of total estimated manhours allows for a straightforward determination of the effect of shift work on labor productivity, instead of measuring loss of labor productivity in terms of weeks or months like many typical labor productivity models.

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 12 from analyzing 17 real projects where shift work was employed during project implementation. The R2 value of the regression is 45.5%, a high value for the type of data analyzed. The p-value of the regression analysis was 0.000, and p-values for predictors were also statistically significant, indicating a relatively strong regression model.

% Productivity Loss due to shift work
= 0.187 + 0.0676 x Ln (%Shift Work) (12)

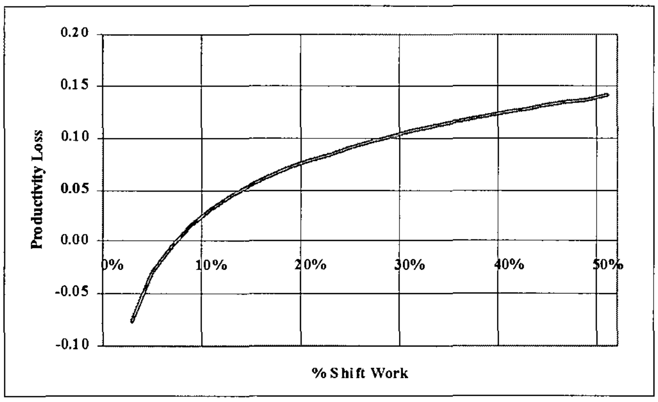

Figure 3. Effect of Shift Work on Labor Productivity

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

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

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

3.3.3 Example Application

As an example, an analysis of project data supplied by a sheet metal contractor from Oregon was examined. The contractor's scope of work on the project was to fabricate and install an HVAC system for the facility. Some part 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 changes during construction. Since not enough time was granted for the increased scope of work, the contractor implemented shift work. The total number of shift work hours was 5,895, representing 20.37% of the total budgeted manhours.

% shift work = 5,895 ÷ 28,938 = 0.2037 (or 20.37%) (13)

These quantities were arrived at by dividing the total number of shift workhours by the estimated total manhours. Inserting the values of 0.2037 for % shift work into Shift Work Equation, a productivity loss of 0.08, or 8% is calculated.

% Productivity Loss due to shift work
= 0.187 + 0.0676 Ln x (0.2037) = 0.08 (or 8%) (14)

Applying this 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 loss of 943 manhours due to the second shift.

Lost manhour due to shift work
= 0.08 x 11,790 = 943 manhours (15)

Therefore, the contractor's lost productivity included a 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 change orders, possible poor management by the contractor, or a low estimate in the original bid.

3.4 Scope of Model

This study is limited to mechanical and sheet metal projects with lump sum contracts and a traditional project delivery system.

4. Conclusion

Among overtime, overmanning, and shift work, no option is always superior to the other two methods of schedule acceleration. However, decision making on the selection of a schedule acceleration method is not solely dependent on how much each methods affect productivity. There are some criteria that can determine the schedule acceleration 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. 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.

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