Impact of Shift Work on Labor Productivity for Labor Intensive Contractor

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Abstract: Generally, a contractor has three options in accelerating a construction schedule: working longer hours, increasing the number of workers, or creating an additional shift of workers. There has been a significant amount of research conducted on scheduled overtime on construction labor productivity. However, little information has been found in the literature addressing the labor inefficiency associated with working a second shift. This paper has qualitative and quantitative components. The qualitative part details why and how shift work affects labor productivity, and then addresses the appropriate use of shift work. The quantitative component determines the relationship between the length of shift work and labor efficiency. The results of the research show that shift work has the potential to be both beneficial and detrimental to the productivity of construction labor. Small amounts of well-organized shift work can serve as a very effective response to schedule compression. The productivity loss, obtained from the quantification model developed through this study, ranges from −11 to 17% depending on the amount of shift work used.

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Introduction

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

The second shift schedule is very effective at reducing project duration, because it allows the amount of weekly work-hours to be approximately doubled. Another reason shift work is sometimes preferred to overtime or overmanning is that the inefficiencies from physical fatigue caused by overtime work and congestion problems associated with overmanning can be avoided by working two or three 8-hour shifts per day. In addition, premium payment to a second shift is typically lower than that of overtime. When a work site is very congested due to overmanning, adding a second shift is a potential solution (Hanna 2003). However, shift work also has disadvantages and introduces additional costs, which will be discussed in detail in the paper.

Problem Statement

Construction labor costs are generally known to be 33–50% of the total project budget (Hanna 2001). In labor-intensive construction, the profit margins are typically 2–3% of the total project budget. As labor is more variable and risky than other project cost components, understanding the effects of a factor on labor productivity is crucial. Compared to other project cost components such as material and equipment, labor costs have more opportunity to improve by good management. An increase in productivity reduces labor cost in direct proportion. It can either amplify or eliminate a project's profit, making it of vital interest to contractors.

Direct costs of shift work are typically charged 15% extra in wages and workers who work for 7.5 h would normally get paid as if they work for 8 h. This amount is approximately 20% extra in wages. Owners are generally willing to pay for the direct costs but not the loss of productivity associated with the shift work. Sometimes the unawareness of shift work's impact forces the owner and contractor into litigation. But, it is hard to determine and quantify the impact of shift work on labor productivity. Much effort has been made to quantify the effects of shift work on labor performance and productivity. Unfortunately, most quantification

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is for industries other than construction, such as manufacturing and nursing. Currently there is no precise way to compute the losses of direct, straight-time labor and productivity due to shift work for the construction industry.

Research Objective

Available research fails to reach a consensus on whether shift work negatively impacts construction labor productivity; however, the majority of studies conclude that it does. Through previously published research, the impacts of shift work on labor productivity are summarized, along with other possible causes of productivity loss. The primary objective of this paper is to quantify the effects of shift work on construction labor productivity. This objective is achieved by addressing the project selection criteria, providing a description of the data set, and formulating a statistical regression model. From the quatification model, a productivity multiplier, which varies depending on the level of shift work, will be provided at the end of this paper.

Research Methodology

Macroanalysis versus Microanalysis

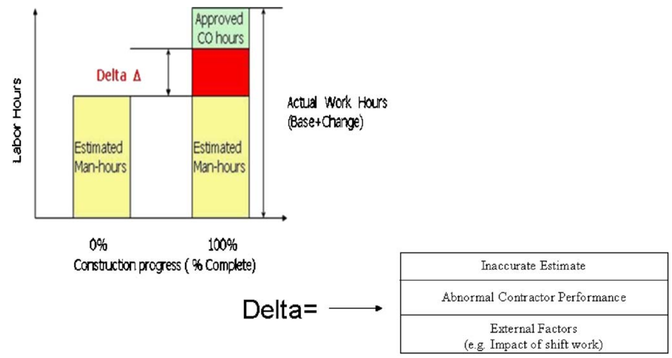
Productivity can be measured on a microscale or a macroscale. The microanalysis of productivity looks at a specific activity of a project. Macroanalysis looks at the project as a whole (Hanna 2001). It is difficult to quantify the impact of shift work on project as a whole through microanalysis. Therefore, macroanalysis was adapted to determine the impact of shift work on labor productivity.

Factors Approach

When schedule acceleration and compression occurs, it results in an increase of the total manhours consumed beyond the budgeted level for completion of the originally contracted work. It is important to note that the amount of work has not changed from the originally contracted amount. The cause of the reduction of efficiency in the performance of labor can be attributed to a number of factors, such as overtime, shift work, overmanning, etc. The cumulative impact of these factors on the productivity of labor equates to the total manhours that are consumed beyond the budgeted level. The factors approach was first introduced by Waldron (1968) and has been adapted for this research. This paper seeks to analyze only the effects of shift work and its contribution to the manhours lost on accelerated projects. The effects of overtime, overmanning, and other impacts are not considered. A graphical representation of the factors approach can be seen in Fig. 1. In Fig. 1, each factor contributes to a portion of the total excess of actual manhours beyond the budgeted manhours.

Labor Cost versus Labor Hour

Labor hour, instead of labor cost, was used as a means to compare projects regardless of their geographic area, time of completion, and size. By using labor hours as a comparison base, all different



$$\%\,Delta = \frac{Total\,WorkHours - (Estimated\,Workhours + Approved\,Change\,Order\,Hours)}{Total\,Actual\,Workhours}$$

Fig. 1. The factors approach

types of projects can be combined into a single database. All factors, including productivity loss and project size, were defined by labor hour instead of labor cost.

Definitions

Shift work is defined as 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. Productivity can be defined in many ways depending on the user. Economists and accountants define productivity as the ratio between total input of resources and total output of product. Therefore, in construction, resource input would include labor, material, equipment, and overhead. Output can be measured as the total dollar value of construction put in place. Conversely, project managers and construction professionals define productivity as a ratio between earned work hours and expended work hours, or work hours used. It should be noted that the latter definition is adapted in this paper.

Effects of Shift Work

In general, the amount of research into shift work directly performed by the construction industry is scarce. This can be attributed to the fact that shift work is less common in the construction industry than in such industries as manufacturing and hospital care. Many local unions required a minimum of one or two weeks of shift work before it is implemented. In addition, many contractors are not using shift work for security reasons as the jobsite is closed after the first shift. As a result, the disadvantages associated with shift work have not been addressed, but merely accepted as the consequences of utilizing shifts. A large amount of studies have been conducted in other industries, particularly in manufacturing and nursing. It is from these sources that the bulk of shift work literature stems. Though not from construction, the data used in these studies attempts to relate the effects of shift work on human performance.

Total project cost of shift work is normally higher than that of normal operation. Shift work introduces other additional costs, including additional administration personnel, supervision, quality control, safety, and lighting, as well as shift differential. Coburn (1997) reported the cost of shift work, strictly speaking, to be the effect of shift work on workers in terms of cost. The author categorized the cost incurred by the use of shift work into

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two groups: Increased health care costs as a result of a shift worker's stressful lifestyle and reduced productivity and increased industrial accidents as a result of a worker's fatigue. The cost of shift work to American industry was estimated in excess of $77 billion (Coburn 1997). It should be noted that 84% ($64.5 billion) of the total cost of shift work is due to reduced human performance at work (Coburn 1997).

The problem associated with shift work is that there is no single point of responsibility for progress and quality, sometimes requiring a period of wasteful overlap for a smooth changeover. Additional problems associated are extensive worker coordination, increased absenteeism and turnover, increased error and accidents, unavailability of timely administrative decisions from higher management, a higher accident rate, light trespassing, and noise impact to nearby residents.

Penkala (1997) and Hung (1992) reported some of the common problems associated with shift work. The problems include: Little cooperation between shifts, inconsistent operating procedures across shifts, inefficient communication between crews, absence of regular business hours for management (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).

The biggest impacts on shift workers are lack of sleep and the difficulty of adjusting the body to new sleeping cycle. Humans are accustomed to working during the day and sleeping at night. Working incongruously with natural preferences affects both an individual's health and job performance. In regards to a sleeping shortage, night-shift workers have about half an hour less sleep time than permanent day-shift workers (Kroemer et al. 1990). Adjustments in body rhythms to a new work-sleep cycle require 7–12 days (Costa 1996), or 24 to 30 days (Fly 1980). Fly (1980) concurred with Hung (1992) 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). Walden (1968) estimated the productivity loss due to shift work to be 10%. 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 indicated that shift workers generate more errors and accidents, and may have difficulties in maintaining proper relationships at the family and social levels (Costa 1996).

Fig. 2 illustrates how labor productivity losses occur when shift work is present. The inputs are situations that require the implementation of shift work. Influencing factors are those situations or conditions that lie outside of management's direction and can increase labor inefficiency. Controlling factors represent conditions for successful application of shift work, whereas outputs are simply some possible results of shift work implementation.

Previous Quantitative Research

A literature review reveals that few studies have been done in order to measure the effects of shift work on labor performance and productivity. The studies are for manufacturing (Thierry et al. 1974; Vidacek et al. 1986), a medical center (Brown 1949; Totterdell et al. 1995), a gas company (Bjerner and Swensson 1955), and a transportation service (Hildebrandt et al. 1974). As shift work studies were made on various industries, performances were measured via various methods. These methods include: waiting time per call of the operators, errors at reading meters, speed of sewing, speed of using spinners, the number of compulsive brake pedal presses, simple unprepared reaction time, etc. The productivity loss reported by the above studies ranges from 3 to 52%. Table 1 summarized the previous studies in terms of relevant industry, type of worker, performance measurement method, and findings on labor productivity in shift work.

Only one meaningful study (Haneiko and Henry 1991) was found on construction operation. The lack of quantitative data is probably due to the infrequent use of shift work in construction. During their investigation and analysis of 5 factors possibly affecting construction productivity, Haneiko and Henry (1991) found that double shifting has an impact on productivity. During the project, double shifting was implemented on electric work for a year. Shift work caused a gradual initial decrease in the unit production rates, followed by a recovery period. This may be attributable to an initial shortage of craftsmen and supervision familiar with the project. This later improved as the additional staff became more familiar with the project (Haneiko and Henry 1991). The decrease in production rate was measured to be a 24–37% depending on the commodity being installed (Haneiko and Henry 1991). The reduction in efficiency lasted approximately seven months, after which productivity improved.

As with the study by Hildebrandt et al. (1974), where shift work had better performance than day-time operation, not all researches concluded that shift work has a negative effect on worker performance. From the analysis of data collected from 36 industries, including electrical and general engineering, Cook (1954) found that no significant reductions in productivity were experienced. Also, Cook indicated that shift work greatly affects neither absenteeism nor safety (Cook 1954). The competition between shifts might actually cause an increase in overall productivity (Horner and Talhouni 1995). Based on company experience, Smith (1987) stated that a well-planned second shift with work completely separate from the first could have a productivity rate greater than the first shift. Shift work avoids the congestion of trades, allows for the optimization of crew size, and improves motivation (Haring 1981). Further, Haring felt that these positives more than offset any potential costs of the implementation of shifts (Haring 1981). Haring recorded labor efficiency saving of 20–25% for the night shift over that of the day shift at a nuclear power plant as an example (Haring 1981). However, the shift work hours constituted only a small portion of the total budgeted work hours for the project, indicating that the savings recorded do not represent scenarios with extensive shift work present.

Data Collection

To study the impact of shift work on labor productivity, the research team collected project data and analyzed it. The research data were collected from geographically diverse specialty trades such as, mechanical and sheet metal contractors. The acquisition of data was done by survey. The questionnaire inquired about the contractor's background information along with specific questions concerning projects that experienced a shift work problem due to schedule acceleration and compression. Questionnaires were distributed to mechanical and sheet metal contractors across the country, with follow-up phone calls and e-mails ensuing. Through data collection process, various factors of projects were

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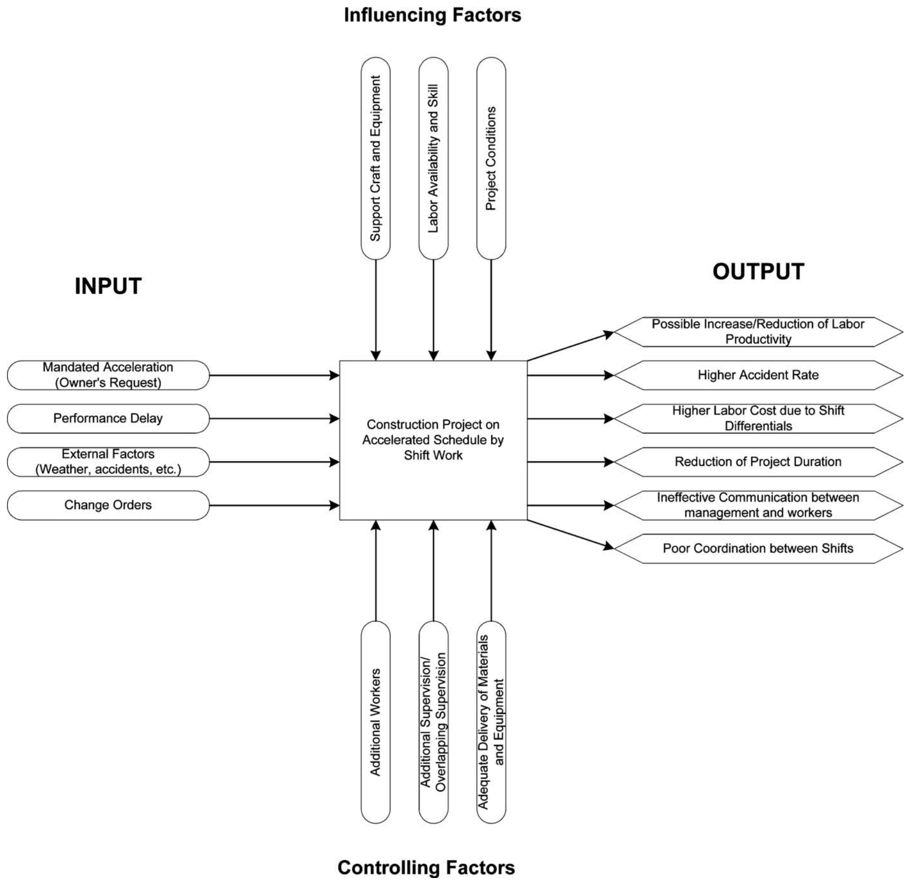

Fig. 2. Schematic structure of shift work (Hanna and Sullivan 2004, with permission)

collected and reviewed. Project data collected by the questionnaire included: Information related to the project type, type of construction (addition, expansion, new construction, renovation, etc.), owner information (private, public, etc.), estimated and actual manpower used for the project, information about the contractor's role (prime contractor, sub, or other), type of contract used by contractor's project management practice, productivity information along with project schedule, and estimated and actual manpower loading graphs.

The databank contains 26 projects which experienced some amount of shift work that is suitable for this study. The sizes of the projects, in terms of manhours, ranges from 3,086 to 550,000 total manhours. Five different types of construction, with performances in 15 states, are represented; these include commercial, industrial, institutional, residential, and manufacturing projects.

Statistical Model Development

Efficiency Loss

Loss of efficiency is defined as the difference between actual hours utilized and earned hours, which includes approved manhours for change orders as a percent of actual total hours utilized. Lost efficiency may result from a contractor's poor performance or the impact of productivity related factors such as overmanning, overtime, shift work, and work interruptions. 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. To compare projects of varying size, percent lost efficiency (% lost efficiency) is defined as given in Eq. (1)

$$\%\text{ lost efficiency} = \frac{\text{Actual total manhours} - (\text{Estimated total manhours} + \text{Approved change order hours})}{\text{Actual total manhours}} \quad (1)$$

Predict Variable: % Shift Work

To determine the effects of shift work on labor productivity, % shift work was considered. The level of shift work utilized on the project was measured by using % shift work. % shift work is defined as total shift work manhours divided by the original, budgeted labor hours for the project

$$\%\text{ shift work} = \frac{\text{Total shift work manhours}}{\text{Budgeted total manhours}} \quad (2)$$

The greater the value of the ratio, the more shift work was used. Measuring shift work as a percentage of total budgeted manhours allows for a more simplistic determination of the effects of shift work on labor efficiency. Measurement in terms of weeks or

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Table 1. Comparison of Studies on the Effect of Shift Work on Performance

Author Year	Brown 1949	Bjerner and Swensson 1955	Hilderbrant et al. 1974	Tilley et al. 1982	Vidacek et al. 1986	Haineko and Henry 1991
Industry	Medical service	Gas company	Railway	Manufacturing company	Electronics component factory	Construction
Type of worker	Female switchboard operators	Three workers rotated on every week	Locomotive drivers	Two groups of six workers	186 female workers	Electrical worker
Performance measurement	Waiting time per call of the operators	Errors to read meters	Errors (the number of automatic compulsive braking)	Simple unprepared reaction time		Production rate
Findings	The delay per call rate in night shift was 52% higher	32.92% higher rate of error during nighttime	Daytime had a 10% higher rate of errors	Workers for the night shift had 25% less sleep The performance level of nighttime shift is 7 or 9% lower	The productivity of night shift worker was 4.5% lower	Gradual initial decrease and then recovery followed
Remarks	During the war	Studied from 1912 to 1931	Reverse result			Duration of shift work: A year

months is not always practical for project conditions and this paper seeks to provide the most usable model that can be developed. The collected data possessed ratio limits of 0.01 and 0.53 for shift hours worked over the budgeted total hours work.

Regression analysis was performed to develop a quantitative relationship between lost productivity (percent lost efficiency) and shift work (shift work hours over total hours); denoting percent lost efficiency (formulated in decimal, not percentage form) as the response variable and % shift work as the predictor. the final model is given as

$$\textbf{Productivity loss} = \mathbf{0.22052} + \mathbf{0.07152}\ln(\%\ \textbf{shift work}) \quad (3)$$

Fig. 3 is a graphical representation of Eq. (3). The "ln" preceding both predictor variables is the natural log function, which was used as a transformation to improve the model. Tables 2 and 3 contain the statistical analysis of the final model.

The productivity multiplier indicates relative productivity under the situation that a certain factor affecting productivity exists. The productivity multiplier can be easily calculated by subtracting productivity loss obtained from Eq. (3) from 1, where 1 represents the productivity under normal conditions. Table 4 shows the productivity multiplier of shift work depending on the amount of shift work.

Scope of the Model

The applicable range of the model given in Eq. (3) is defined by the data used to formulate the regression. For the model to be valid to a project, it must have a size between the range of 3,000–550,000 total manhours. The range of % shift work is between 0.01 and 0.53. If a mechanical or sheet metal project is within these values, Eq. (3) can be implemented to determine the impact of shift work on labor productivity.

Comparison to Previous Studies

Direct comparison to previous studies on different industries may not be so effective due to the different types of work and workers investigated, as well as the different measurement approach utilized to measure the effect of shift work on performance. However, an overall trend may be found in comparing findings. The efficiency loss from −11 to 17% is obtained from the quantification model developed through this study for the shift work consisting of 1–50% of the budgeted total manhours. It is lower than the results of two studies done before the 1950s. As the data used for these two studies are outdated, a more meaningful comparison was drawn to studies done after the 1960s. The study results on productivity loss due to shift work reported after the 1960s are: 10% (Waldron 1968), −10% (Hildebrandt et al. 1974), 7–9% (Tilley et al. 1982), and 4.5% (Vidacek 1986). All of these are quite identical with efficiency loss as defined by Eq. (3).

Haneiko and Henry (1991) found that the implementation of a second shift reduced overall productivity by 24–38%. This is somewhat higher than the results of this study. This difference may come from two reasons. First, an exact equivalent measure cannot be given due to the lack of data provided by Haneiko and Henry. Second, the productivity loss might come from the use of a combination of shift work and overtime, rather than solely from shift work, judging from their study result showing that the impact of double shifting on productivity varied over time. Haring claimed a 20–25% savings in productivity during the night shift (Haring 1981). The amount of shift work used constituted about 1% of the total project hours. Inserting this value into Eq. (3) yields an 11% savings of productivity. This value is slightly lower than the findings reported by Haring, however both values moved in the same direction.

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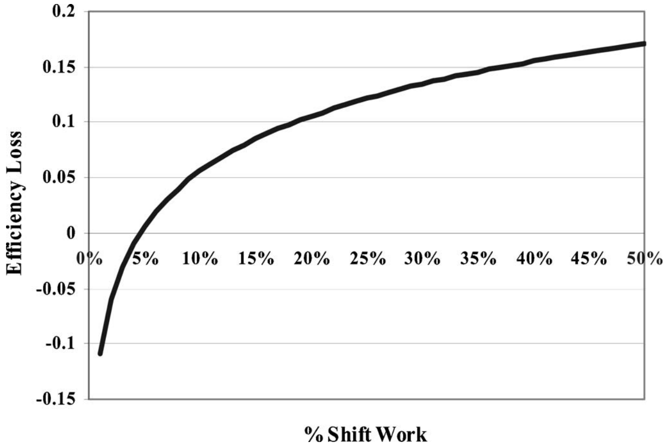

Fig. 3. Effects of shift work on labor productivity

Validation

The final model was validated through the cross-validation method. In cross validation, the collected data is randomly segmented into five subgroups. The model was refit using four subsets, with the remaining 20% of the data then used to predict the model's accuracy and precision. This process was repeated for all five subsets. The result shows the equation seems to be more accurate for the project experiencing small amounts (less than 20%) of productivity loss. The difference may come from specific project conditions or a contractor's ability to manage the project.

Case Study

The model presented as Eq. (3) is applied in a case study to demonstrate how to use the equation in actual scenarios. As an example for the use of the shift work model developed, an analysis of project data supplied by a sheet metal contractor from Hilsboro, Ore., will be examined. The focus of the example is to quantify the impacts of shift work on the project through the use of estimated labor hours versus actual labor hours.

Contractor's scope of work on the project was to fabricate and install HVAC system for a facility. Some part of the work was executed on an existing operating unit. The budgeted manhours for the project were 28,938 h and the actual manhours expended at the conclusion of the job were 56,822. The project lasted 35 weeks, including a 9 week time extension due to the large amount of change orders during construction. As not enough time was granted for the increased scope of work due to the change orders, 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. These quantities were arrived at by dividing the total number of shift hours by the total budgeted manhours.

Table 2. Analysis of Variance for Shift work Regression Equation

Source	Degrees of freedom	Sum of squares	Mean square	F	P-value
Regression	1	0.51263	0.51263	22.83	<0.001
Residual error	24	0.53899	0.02246		
Total	25	1.05162			

Table 3. Hypothesis Testing Result for Shift work Model Predictor Variables

Coefficient tested	Null hypothesis	Alternative hypothesis	P-value	Result
ln(%SW)	Equal to zero	Not equal to zero	<0.001	Not equal to zero

As the project size is within the applicable limits of the regression model, as are the ratios of total shift work and budgeted total manhours, Eq. (3) may be used. Inserting the values of 0.2037 for % shift work into Eq. (3), a productivity loss of 0.1067, or 10.67% is calculated. Applying this percentage to the 11,790 total hours worked during the use of shifts (5,895 by the first shift and 5,895 manhours by the second shift) gives a loss of 1,258 manhours ($11,790 \times 0.1067 = 1,258$) due to the second shift.

The data defines the contractor's inefficiency as 1,258 manhours as a result of using shift work. This is 15% of total efficiency loss (8,348 manhours) of the project. The remainder of the lost manhours over the course of the project can be attributed to the overmanning, overtime, change orders, possible poor management by the contractor, or a low estimate in the original bid.

Successful Application of Shift Work

Several contacts with industry professionals have revealed some techniques to reduce productivity losses and improve the performance of labor during shift work. The study team would like to

Table 4. Productivity Multiplier for Shift Work

% shift work	Productivity multiplier
2	1.059
4	1.010
6	0.981
8	0.960
10	0.944
12	0.931
14	0.920
16	0.911
18	0.902
20	0.895
22	0.888
24	0.882
26	0.876
28	0.871
30	0.866
32	0.861
34	0.857
36	0.853
38	0.849
40	0.845
42	0.842
44	0.838
46	0.835
48	0.832
50	0.829

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provide recommendation about how to mitigate the impact of schedule compression on labor productivity.

- **Overlapping management—**The contractor must overlap the management of the project so that the arriving crews are aware of the what has been completed by the previous crews. This can be accomplished by requiring the foreman of the first shift to stay 1–2 h longer and the foreman of the second shift to arrive 1–2 h earlier.
- **Selection of work assigned to a second shift—**Assigning completely different tasks to the second or third shift can improve shift operations. These tasks should be totally independent from the tasks performed by the previous shift, including different materials and tools.
- **Be selective on the work assigned to a second shift—**Due to the difficulties in managing shift schedule, it is recommended that a second shift be used only for a well-defined scope of work that does not require much engineering and design support. A smaller scope facilitates coordination, planning, and supervision of the second shift.
- **Material requirements—**For the successful application of the shift work concept, material requirement should be minimal, as most supply stores are closed during the working hours of second and third shifts.
- **Avoid congestion—**Shift work can be most effective if used when a work area during normal hours is extremely congested by additional craftsmen and other trades.
- **Sufficient amount of artificial lighting—**When working a second shift schedule, safety is improved greatly by providing a sufficient amount of artificial lighting.

Study Limitations

This study is limited to mechanical and sheet metal projects with lump sum contracts and a traditional project delivery system. However, quantitative data can be expanded to other labor-intensive projects. It should also be noted that due to the relatively small sample size of contractors surveyed (26), the equations which were derived may be slightly skewed.

Conclusions

Shift work has the potential be both beneficial and detrimental to the productivity of construction labor. Small amounts of well organized shift work can serve as a very effective response to schedule acceleration. Through the quantification model, easy-to-read graph and table, contractors have the ability to determine the impact of shift work on labor productivity and practically to calculate productivity loss and labor cost, due to shift work. Use of this equation can also serve as a beginning to negotiations between owners and contractors for adjustments due to owner initiated schedule acceleration and compression. Further, a contractor will be able to select its best option (i.e., overmanning, overtime, and shift work) when schedule acceleration is required. The positive effects of shift work on productivity make it a preferable option in place of overtime or overmanning. However, the coordination problem it presents and health problems it can raise in the workers must also be considered when making the decision of how to accelerate a schedule.

Recommendations

Shiftwork is an effective schedule compression technique in labor intensive construction if it is used for a short duration. This study showed that the use of second shift labor for an extended duration can have a significant negative impact on labor productivity. The major source of labor inefficiency in shiftwork stems from overlapping the first and second shift. It is recommended to overlap supervisions of the two shifts by asking the supervisors of the first shift to stay longer and the supervisors of the second shift to arrive earlier. It is also recommended, if possible, to assign completely different tasks at different locations to second shift workers, than those of the first shift. For shift work to be successful, it has to be planned carefully, as most material suppliers are closed during much of the shiftwork duration. In addition, careful safety evaluation should be conducted due to the potential negative impacts resulting from artificial lighting and disturbance of normal sleeping hours.

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