

**2020 NEI Report of Project Management Lessons Learned and Best Practices
Construction of New Nuclear Power (NNP) Plants
32 Public Domain Reference Documents**

2017

**Industry Reference Document (24) of (32)
Construction Productivity Impacts due to
Extended Work Weeks, Shift Work, & Fatigue
85 pages**

High Bridge Associates, Inc.
Compilation and Analyses of Public Domain White Papers

Background and Introduction - The overall scope of technology, labor, equipment, and material associated with large light water reactor (LLWR) NNP projects is enormous. Plant arrangements and redundant engineered safety systems result in significant bulk quantities and congested workspaces that create limits on the pace of construction installation that drive schedule duration and overall costs. These LLWR NNP projects have typically adopted various combinations of overtime, extended work weeks, and multiple shifts with the goal to reduce schedule durations and related costs. Additionally, off-site system/component modularization techniques have evolved to reduce schedule duration and costs by conducting off-site manufacturing and factory assembly of mechanical/electrical assemblies/modules integrated with on-site structural construction installation activities and on-site pre-assembly regimes.

SMR technology offerings are based on various reactor cooling and steam generation design concepts. These are aimed at reducing the size and quantities of systems and components and increasing what scopes can be factory manufactured and shipped to the site rather than stick-built at the site. Many designs include passive safety concepts to eliminate systems and additionally reduce construction quantities. While 5% to 10% of the capacity of LLWR designs, many smaller capacity SMR and AR nuclear steam supply systems still involve components approaching the dimensions and sizes of LLWR system components. All SMR and AR designs are FOAK projects and many have significant construction quantities to be installed, approaching 50% or more of those involved with LLWR designs. Labor congestion issues and schedule efficiencies for SMR and AR NNP construction remain as critical to achieve required economic capital cost performance expectations. While micro-reactor designs are under development to offer a “plug and play” approach and dramatically reduce construction costs and schedules, licensed designs with committed customers are not in the near term.

Developing the work week, hours per day, and shift basis approach for an NNP project schedule is a challenging task. There is no one size fits all approach that will provide an optimum solution. History shows that intensive planning and evaluation of many past practices is required to develop a realistic plan and approach that addresses local labor pool, travel times, competing projects, fatigue, work continuity, and other factors. The primary need for utilizing a combination of overtime, extended work weeks, and multiple shifts in the past has been to improve cost/schedule labor efficiency and reduce schedule durations and indirect/distributable related costs. This need remains a significant reality for future NNP projects of LLWR, SMR, or AR design basis. Additionally, many NNP projects have evaluated and concluded that offering 50-hour work weeks was necessary to compete with other construction projects (power and industrial) and to attract the necessary numbers of qualified construction workers.

NNP projects will involve organized union labor and open shop labor pools, and these facts must be recognized. Regardless of the labor pool, history has shown that work continuity and labor fatigue resulting from extended work weeks and 2nd shift work cause major productivity losses. As discussed earlier, spending more hours per person over a prolonged time period creates a point of diminishing returns where the additional hours do not contribute to more production due to fatigue. This has been studied and documented many times over the past.

Using a 1st and 2nd shift approach with each shift working 5/10s for a 50-hour work week may define a mathematical basis for achieving a 25% schedule reduction by working 25% more hours in any given work period. However, the productivity losses, fatigue factors, absenteeism, and work management continuity impacts using this approach are significant and documented very well. We performed a search of public domain information regarding the productivity impacts of overtime/extended work week and second shift work. Industry guidance and White Papers generally view that a combined extended work week and second shift program should be used sparingly to implement critical path corrective action or alleviate congestion. The following white papers (**See Attachment A**) contain relevant material and insights:

1. Calculating Loss of Productivity Due to Overtime Using Published Charts – Fact or Fiction by Regula Brunies and Zey Emir, Revay and Associates Limited, 2001. This paper researched and summarized information from 15 publications.
2. Impact of Extended Overtime on Construction Labor Productivity by Awad S. Hanna, Craig S Taylor, and Kenneth T. Sullivan, 2005 ASCE Journal.
3. Shift Work Impact on Construction Labor Productivity by Awad S. Hanna, Chul-Ki Chang, Kenneth T. Sullivan, and Jeffrey A. Lackney, 2005, ASCE Journal.
4. Scheduled Overtime Effect on Construction Projects, Business Roundtable Report C-2, November 1980.
5. Effects of Scheduled Overtime on Labor Productivity by H. Randolph Thomas, 1992.
6. Quantifying the Impact of Schedule Compression on Construction Labor Productivity by Chul-Ki Chang, Awad S. Hanna, Jeffrey A. Lackney, and Kenneth T. Sullivan, 2005, ASCE.

Productivity Loss Due to Overtime/50 Hour Extended Work Week – Overtime Fatigue Paper 1 (above) is a very comprehensive study and provides information from various industry leadership sources including the US Bureau of Labor Statistics (BLS), Construction Industry Institute (CII), US Army Corps of Engineers (COE), The Business Roundtable, AFL/CIO building and construction trades, American Society of Civil Engineers (ASCE), Mechanical Contractors Association, National Electrical Contractors Association (NECA), and other sources. ***These suggest a productivity loss of about 30% will be experienced when working more than 40 hours/week using a single shift of 5 workdays at 10 hours per day and 50 hours/week for an extended period of 12 weeks or more. We conclude that a craft labor productivity loss of 25% to 30% is likely for the 5/10s 50-hour work week approach.***

Productivity Loss Resulting from Extended Shift Work – 2nd Shift Continuity Inefficiencies Paper 3 is a study of 2nd Shift Work Impact on Construction Labor Productivity published in 2005 in the ASCE Journal. ***It suggests an approximate 13% productivity loss due to shift work for a project performing 20% to 30% of the work on a second shift.*** Our experience indicates a 15% impact due to the 2nd shift effort is likely. This was also the 2nd shift impact value used by the AFL/CIO and major EPC contractors in 1979 as part of their study for developing the Nuclear Power Construction Stabilization Agreement (NPCSA) and Alternating 4/10s shift work approach instead of the 5/10s approach.

Labor Efficiency/Shift Work Lessons and Practice Conclusions - These prolonged 5/10s and 50 hour work week fatigue factors coupled with 1st/2nd shift continuity work penalties or negative “Lessons Learned” from nuclear industry experience last century united the AFL/CIO Building and Construction Trades Department, Bechtel, Ebasco, Stone and Webster, and United Engineers to adopt the Alternating 4/10s Shift Work Approach and Nuclear Power Construction Stabilization Agreement (NPCSA) in the early 1980s (See **Reference Document 1**). This approach was evaluated as a better work week and shift schedule approach to mitigate these productivity/fatigue/continuity losses and accelerate schedules with higher confidence and reduced risks.

Alternating 4/10’s Shift Work Approach and NPCSA – As outlined in **Reference Document 28** of this NEI Report, many elements and issues need to be considered and evaluated when looking at the benefits and challenges of moving to an Alternating 4/10’s shift approach for a project. Based on extensive High Bridge records and studies on this, the issues are complicated and perhaps not obvious to those who have not worked various construction work shift scenarios.

Figures 1, 2, and 3 provide graphics that summarize the parameters of the Alternating 4/10's vs. 5/10's shift work approach, along with the resulting benefits for:

- Improved productivity due to 40-hour work week followed by 4 days off
- Reduced shift staffing levels and congestion,
- Reduced 1st and 2nd shift production work handovers,
- Reduced craft absenteeism,
- Reduced weekly worker hours,
- Reduced worker fatigue,
- Reduced round trips to the job,
- Nearly double the weekend time off, and
- Pay rate equalization to yield annual work hours

These factors all combine to produce significantly improved productivity in the 25% to 35% range.

Figure 1 – Alternating 4/10's Shift Work Approach Teams and Calendar

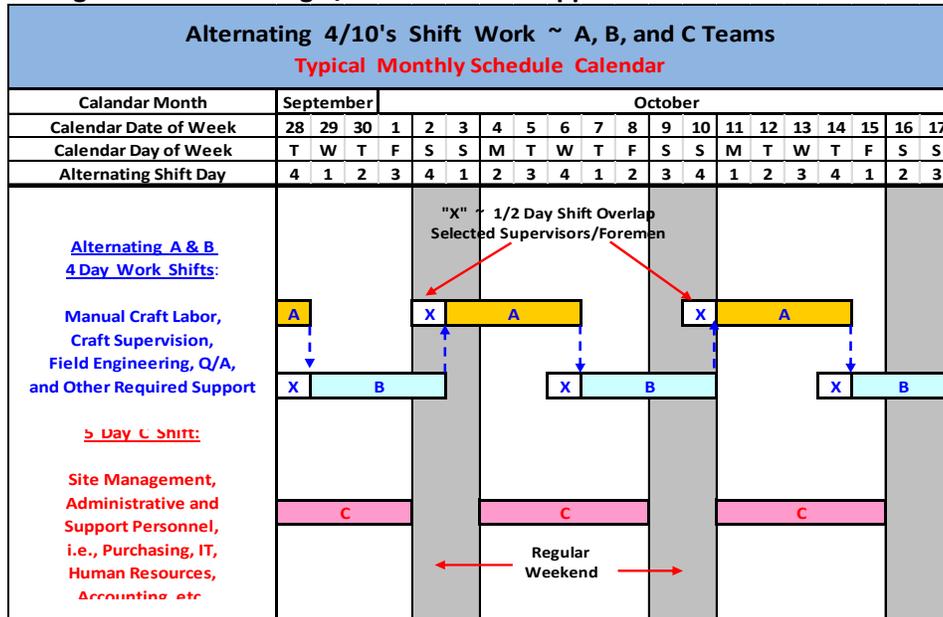


Figure 2 - Alternating 4/10's vs. 1st/2nd Shift Change Hand Offs

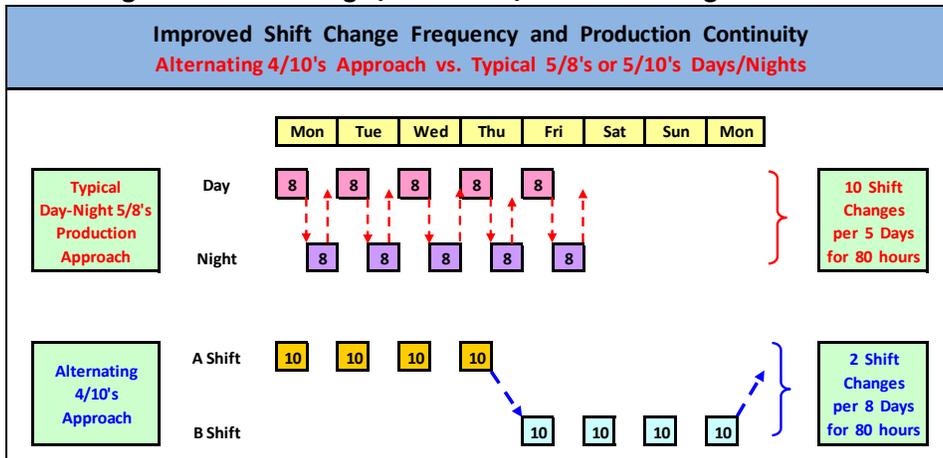


Figure 3 - Alternating 4/10's vs. 5/10's Shift Days Worked and Days Off Benefits

Alternating 4/10's Approach vs. Typical 5/8's or 5/10's Days/Nights Improved Approach Reduces Labor Fatigue/Absenteeism and Attracts Dedicated/Skilled Labor	
	Work Days per Year 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360
Traditional 5 day work week & 2 day weekend	52 work weeks x 5 days/week = 260 work days/year/shift
	52 weekends x 2 days = 104/weekend days/year
	Nearly double liesure time off
Alternating 4/10's 4 day work week & 4 day weekend	45 work weeks x 4 days/week = 180 work days/year/shift
	45 weekends x 4 days = 180/weekend days/year
Alternating 4/10's A & B Shifts Resulting Work 360 Days/Year	90 work weeks x 4 days/week = 360 work days/year
The labor fatigue impact of 1.25 to 1.30 experienced with a prolonged 5/10's 50 hour overtime work week is ELIMINATED	
1. A 45 week work year represents 1,800 work hours/year/worker or 15% less than a 52 week year with 2,180 hours. Crafts are paid a premium time rate to off-set the lost work hours. The increased wage rates and significant leisure time creates a win/win situation with labor.	
2. Work force morale is improved, job fatigue is reduced, and production is enhanced. The crafts enthusiastically support this 4/10's approach with 180 versus 104 weekend days off/year. This then attracts higher skilled, dedicated, and quality conscious resources.	
3. The 4 day weekend creates a larger travel radius and allows more travel/off time that attracts higher quality crafts locally, an expanded resource pool of craft travelers, competes effectively with other construction projects, and reduces nights away from home.	
4. Craft labor absenteeism is reduced and daily work plans are supported more effectively. This is a result of the work force embracing and preferring the 4-day on/off approach. Workers are ready to return to work and less likely to skip one work-day that is 10 hours of wages vs. 8.	
5. Craft staffing levels and congestion on day shifts are reduced by 35% to 40%. This is a result of A and B day shifts having roughly equal craft staffing levels, compared to a day/night shift approach where the day shift represents 70/80% of staffing and night shift represents 20/30% of staffing, which creates day shift congestion peaks.	

- **NNP arrangements and redundant engineered safety systems result in significant bulk quantities and congested workspaces that create limits on the pace of construction installation that drive schedule duration and overall costs.**
- **As all SMR and AR designs are FOAK and have significant construction quantity and congestion issues, the labor and schedule efficiencies for NNP construction are as critical as with LLWR designs to achieve required economic capital cost performance expectations.**
- **The primary need for utilizing a combination of overtime, extended work weeks, and multiple shifts in the past has been to improve cost/schedule labor efficiency and reduce schedule durations and related costs.**
- **Numerous comprehensive industry studies indicate a productivity loss of about 30% will be experienced when working more than 40 hours/week using a single shift of 5 workdays at 10 hours per day and 50 hours/week for an extended period of 12 weeks or more.**
- **The Nuclear Power Construction Stabilization Agreement (NPCSA) from the late 1970's (See Reference Report 1) evaluated the Alternating 4/10's Shift Work Approach as a better work week and shift schedule approach to mitigate these productivity/fatigue/continuity losses and accelerate schedules with higher confidence and reduced risks.**
- **FOAK construction projects may achieve better cost and schedule performance using 10CFR50 rather than 10CFR52.**

Attachment A

Public Domain White Papers Regarding

Shift Work and Overtime Impacts on Craft Labor Productivity

PAPER 1

**“Calculating Loss of Productivity Due to
Overtime Using Published Charts – Fact or Fiction”
by Regula Brunies and Zey Emir,
Revay and Associates Limited, 2001**

Calculating Loss of Productivity Due to Overtime Using Published Charts – Fact or Fiction

*By Regula Brunies, FPMI, CCC, CQS and Zey Emir, P.Eng, MBA
Revay and Associates Limited*

INTRODUCTION

In simple terms, productivity is defined as the measure of output (the work produced in units) per unit of input (hours required or cost incurred). Other frequently used productivity measurements include:

$$\frac{\$ \text{ revenues}}{\text{hours worked}} \quad \frac{\$ \text{ revenues}}{\$ \text{ actual cost}} \quad \frac{\text{hours earned}}{\text{hours worked}}$$

The most convincing method of measuring loss of productivity is undoubtedly the "measured mile" approach. It compares productivity achieved during unimpacted periods or "normal periods" with the productivity achieved during periods affected by the causes alleged. It is based on actual data and inherently accounts for contractor inefficiencies and/or estimating errors. The damages are calculated based on the difference in productivity rates.

Unfortunately this method is of no help if:

1. the required data for a detailed productivity analysis are not available or are unreliable;
2. several causes contributed to the productivity loss, but only one cause is compensable;
3. the productivity loss has to be included in a change order quantification prior to the execution of the change (forward costing).

Short of "guesstimating", the only alternate method for quantifying a distinct productivity loss may be the use of published studies for the cause in question, but not without the greatest caution.

Contractors and their claims consultants often rely on studies which have very little to do with the specific situation under scrutiny. In fact, they may have never examined the actual study and simply relied on a single chart reproduced in a book or by a trade association.

This article examines the numerous studies available for loss of productivity due to overtime. The objective is to inform the user of their often limited application and the pitfalls of erroneous application.

LOSS OF PRODUCTIVITY DUE TO OVERTIME

Overtime in construction is usually defined as work performed over 40 hours per week, or in some instances, more than eight hours in one day.

The most cited factor affecting productivity during scheduled overtime is physical and mental fatigue. Other factors which may contribute to a productivity loss include:

- absenteeism, accidents;
- reduced supervision effectiveness;
- shortage of materials, consumables or tools due to accelerated pace; and
- tardy processing of engineering questions and requests for clarifications due to greater demand within a given period.

Whenever loss of productivity due to overtime is quantified, the surrounding circumstances must be clearly understood.

Bureau of Labor Statistics

The oldest study on overtime, widely cited as a reliable source, dates back to the 1940s. This study by the Bureau of Labour Statistics of the U.S. Army Department of Labor (BLS) is based on 78 individual cases covering 2,455 men and 1,060 women working in a wide variety of manufacturing industries with the work being mostly highly repetitive, machine paced, performed indoors and requiring little decision making. Moreover, this work was performed by incentive wage employees during wartime, on prolonged overtime schedules. According to the BLS study, average productivity for 50-hour, 60-hour and 70-hour weeks were 92%, 82% and 78% respectively.

Notwithstanding the fact that this study was limited to the manufacturing sector, the Mechanical Contractors Association of America (MCAA) relied on these BLS data when it issued its Bulletins no. 18A and 20 in 1968, to assist contractors in the preparation of claims and change orders relative to loss of productivity due to overtime. In 1994 the MCAA, in its M3 publication entitled "Change Orders, Overtime and Productivity", still included the same BLS information as a reliable source to prove overtime inefficiency. Since the BLS data were gathered in a very specific environment in the manufacturing sector, the BLS results and the MCAA charts are of little use for quantifying loss of productivity in construction.

Foster Wheeler

L.V. O'Connor, Director of Construction of the Foster Wheeler Corporation published a paper in 1969 entitled "Overcoming the problems of Construction Scheduling on Large Central Station

Boilers": The paper describes Foster Wheeler's research conducted from 1963 to 1968. Figure 1 shows Foster Wheeler's overtime inefficiency curves derived from its own data. The paper does not disclose how and under what circumstances the data were obtained. Although not explicitly stated, it is presumed that the findings are based on the boilermaker trade. Average productivity for 5-10 hour days and 6-10 hour days were 87% and 73% respectively.

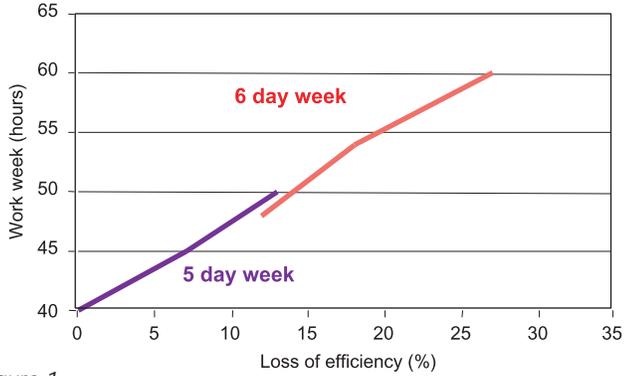


Figure 1

Proctor & Gamble

The Business Roundtable (BRT) issued a task force report in 1980 entitled "Scheduled Overtime Effect on Construction Projects" which was an update of their 1974 report entitled "Effect of Scheduled Overtime on Construction Projects". The original data relied upon were actual project records derived from a series of short jobs over a 10-year period in the 1960s and originated from a single project, namely the Proctor & Gamble Green Bay, Wisconsin process plant. The output was recorded from physical count or measurement, the input was based on actual payroll hours. It is reported that the work was carried out in a tranquil labour climate with excellent field management. The nature of the construction activities and the trades involved are unknown.

Figure 2 depicts the cumulative effect of overtime on productivity for 50- and 60-hour work weeks as per the BRT Study. The measure of productivity is a comparison of actual work hours expended for preplanned operations with a fixed standard base of calculated work hour requirements called a "bogey". The "bogey" standard is for a straight-time schedule. The data are not a comparison of actual straight time with actual overtime productivity.

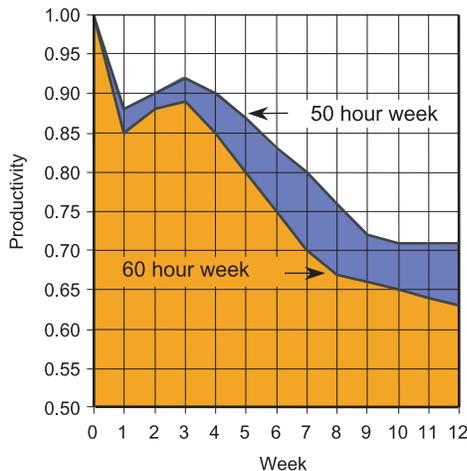


Figure 2

Figures 3a and 3b reflect the ratios of productive return to overtime hours for long-term job schedules of overtime operations: the curves reflect the average and the range of expected performance. It is important to note that after several weeks of overtime, the reduced labour productivity reaches the point of no return. The study also suggests that a 45-hour job schedule very quickly becomes nothing more than wage inflation. It is important to note that the effect of reduced labour productivity reaches the point of no productive returns on overtime hours, earlier for a 50 hour schedule than for a 60 hour schedule. However, the inflated cost per hour of productivity effect is greater for the 60 hour schedule.

The study contains the following warning:

"The industrial firm's data on productivity is based on Fixed Standards, and a performance of 1.0 may not be the same as a performance of 1.0 referenced to some other standard of comparison. As a result, a 30% reduction of productivity in one set of data could compare with a 15% reduction reflected in another set of data due to these differences."

In 1973, the American Association of Cost Engineers (AACE) published a report on the "Effects of Scheduled Overtime on Construction Projects" where it relied on the BRT data. Similarly, "The Owner's Guide to Overtime, Construction Costs and Productivity", published in 1979 by the Associated General Contractors, the American Subcontractors Association and the

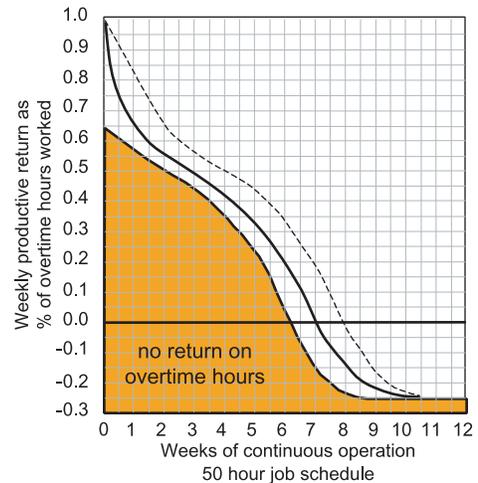


Figure 3a

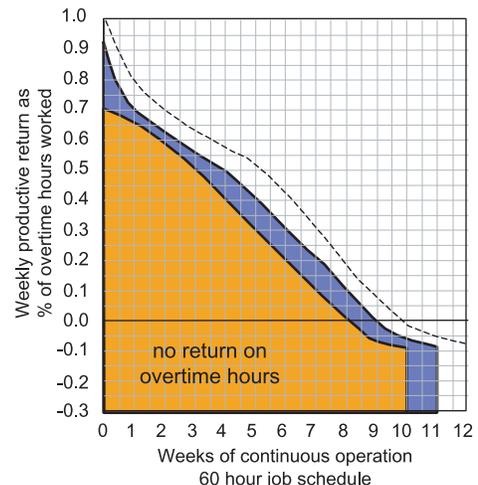


Figure 3b

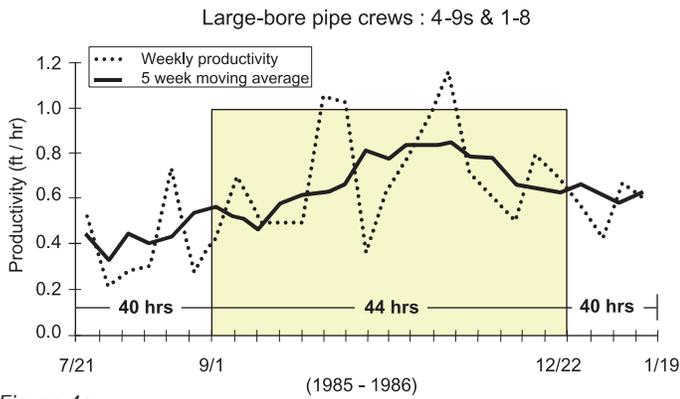


Figure 4a

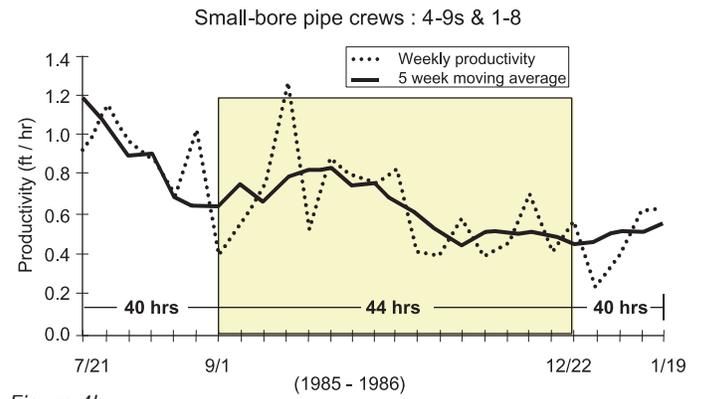


Figure 4b

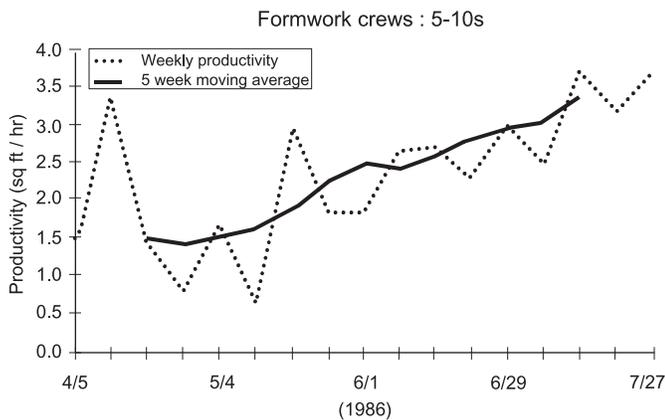


Figure 4c

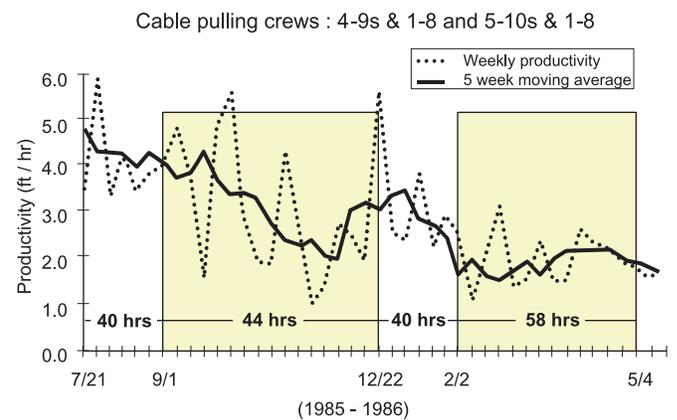


Figure 4d

Associated Specialty Contractors relied on the same BRT data. Finally, the 1994 MCAA publication includes the same BRT data as proof of the relationship between overtime and the increasing ratio of inefficiency during consecutive overtime periods. Thus, all three publications contain no original data and the limitations of the BRT Study are equally applicable.

Construction Industry Institute

In 1988, the Construction Industry Institute (CII) published Source Document 43 on "The Effects of Scheduled Overtime and Shift Schedule on Construction Craft Productivity."

This study contains original data collected between 1984 and 1988 from seven different U.S. heavy industrial projects at various stages of completion, including oil refineries, natural gas recovery plants, a fossil power plant and a chemical processing unit. The focus of the data is on crew performance. Trades involved are primarily electricians, pipefitters and insulators. Two projects include data for concrete crews (labourers) and one project includes formwork and rebar crews (carpenters and ironworkers). Only two projects include data on straight-time as well as on overtime schedules. On the chemical processing unit all tradesmen worked on a rolling 4-10 hour day schedule (two days off); three crews were shifted such that at least two crews were on site every day. Figures 4a to 4d depict the results for selected crews.

Figures 5a and 5b show the curves produced for average normalized productivity against time for various combinations of overtime schedules. They were generated to illustrate overall results of the study.

Based on the inconsistent patterns, no defensible conclusions could be developed with respect to overtime inefficiency. Thus it

is not surprising that the study concludes with the following statements:

1. Previous studies by BLS, the Business Roundtable and others are not consistent predictors of productivity loss during overtime schedules for construction projects in this study.
2. Even on the same project working an overtime schedule, productivity trends of individual crews are not consistent.
3. Productivity does not necessarily decrease with an overtime schedule.
4. Absenteeism and accidents do not necessarily increase under overtime conditions."

In 1994, the Construction Industry Institute (CII) issued Source Document 98 on "Effects of Scheduled Overtime on Labour Productivity: A Quantitative Analysis," the most comprehensive report since the BRT report (1974; 1980). It is based on 151 weeks of data collected from 1989 to 1992 from four active industrial construction projects (papermill, manufacturing, process plant, refinery) without major contract disputes. Each was constructed in a tranquil environment and was well managed. The overtime schedule was used to maintain the schedule, not to attract labour. The manufacturing and papermill projects were existing facilities where old systems and equipment were removed and replaced with new ones. Congestion was a major concern. The refinery involved the rebuilding of an existing facility. The process plant was a spacious, outdoor, grass-roots facility.

The focus of the study was on detailed observation of piping and electrical crews, rather than on various trades. The rationale that only piping and electrical trades were studied is that these trades represented the majority of the work and were most likely to be

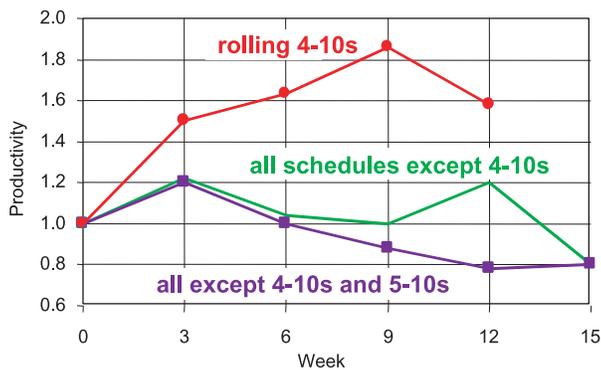


Figure 5a

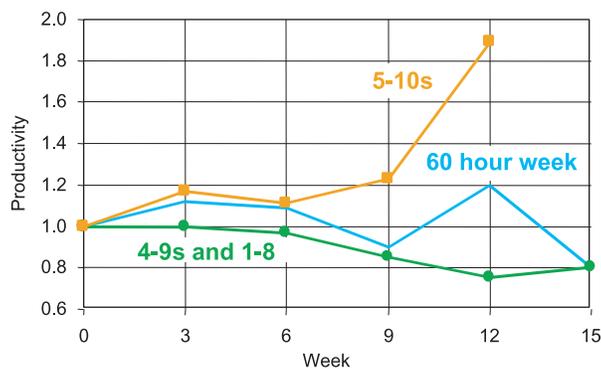


Figure 5b

affected by scheduled overtime. For electricians, the work involved the installation of conduit, cable and wire, terminations and splices, and junction boxes. For piping, work included pipe erection and the installation of supports and valves. The performance of a crew on an overtime schedule was compared to the same crew on a straight-time schedule. There were not data for 5-8 hour days. Therefore a 4-10 hour day schedule was used as the baseline. Work weeks shorter than four days usually were shortened because of weather. There was one 7-day work week which was discarded. Over 90% of the work days were 10-hour days. The study specifically excluded the early phase of the work and the start-up phase.

Figure 6 shows the overtime efficiency (3-4 week duration) as a function of the number of days worked per week. It is obvious that 2- and 3-day work weeks were significantly less efficient than the normal 4-day work week, probably because of the effects of

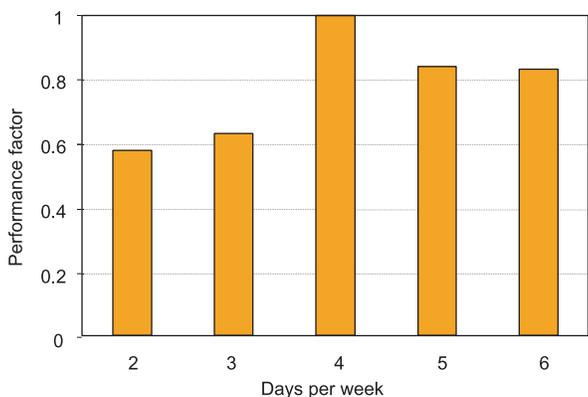


Figure 6

adverse weather. The loss of efficiency for the 5- and 6-day work week was in the range of 10 to 15 percent with very little difference between the 5- and 6-day work week.

The remaining analyses contained in this study were an effort to support the initial determination that there are productivity losses when working overtime. Figures 7a and 7b show the efficiency trends for 50-hour and 60-hour weeks as a function of time compared to the curves from the 1980 Business Roundtable Study. All curves except the BRT curves were normalized about the first week of overtime for better visualization of trends. It is evident that some crews follow the general downward trend established in the BRT Study, while others do not.

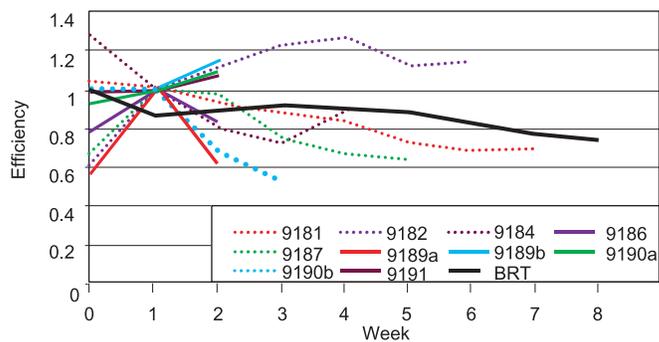


Figure 7a

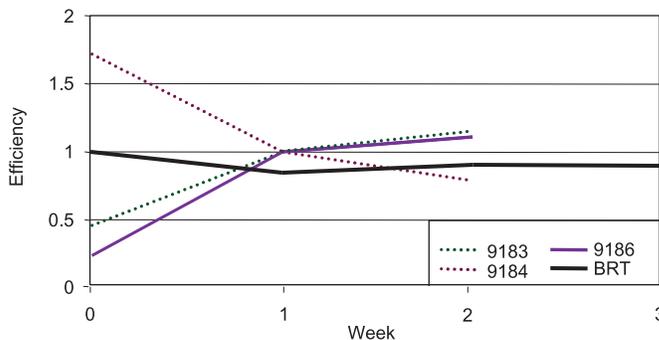


Figure 7b

Figure 8 shows the average overtime efficiency of all crews working a 50-hour work week, the BRT curve and other references. The study concluded that the data are consistent with the BRT curve and that the BRT curve is probably a good representation of the industry average but individual work may vary appreciably. Moreover, the study showed that it was possible to work overtime for three to four weeks without losses of productivity which would be consistent with the 1988 CII study.

In the final conclusion, the study states:

- "The use of short-term overtime can cause a loss of labour efficiency. The average loss was in the range of 15%. When losses were analyzed as a function of time, the averages were consistent with the Business Roundtable curve. However, overtime losses are not automatic but can range from none to 25% for crews (projects) where there are no other factors affecting productivity. Examples of factors that can cause losses greater than 15% are incomplete design, numerous changes, work in an operating environment or labour unrest.
- As overtime efficiency decreases, the research found that there was an increase in disruptions. The most consistent increase occurred in the category of resource availability. It is

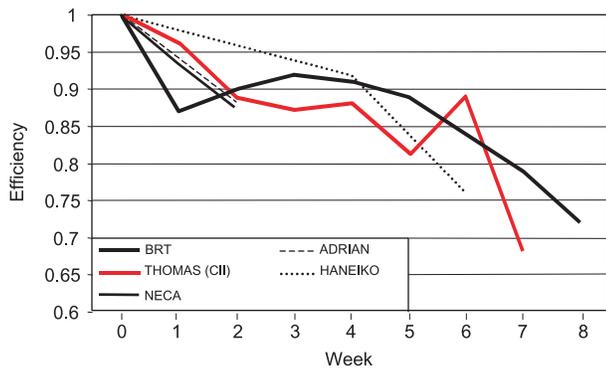


Figure 8

concluded that this increased difficulty in providing resources is the root cause of losses of efficiency.

- The data collection and analysis methodologies are a sound, reliable way to measure the effects of scheduled overtime. The basis for this conclusion is that the results of the analysis are consistent and in line with what would be reasonable."

[emphasis added]

Needless to say, the rather vague quantitative conclusions render their application to a loss of productivity calculation highly questionable. However, this study could be construed as a validation of the BRT curves (in spite of the warning expressed in the BRT study) and the apparent contradiction of the CII 1988 conclusions.

National Electrical Contractors Association

The National Electrical Contractors Association (NECA) published several studies on overtime.

In a 1962 survey, 289 members replied to four questions concerning overtime on a sporadic, short-duration basis and two questions concerning continuous overtime over several successive weeks. This is an extremely small sample considering that NECA has thousands of members. The responses yielded the following average values of productivity.

NECA concluded that the observations were close enough to give

FOR SPORADIC EXTENDED DAYS IN AN OTHERWISE NORMAL WEEK

SCHEDULED DAYS	SCHEDULED HOURS	ACTUAL HRS EXTENDED DAY	PRODUCTIVITY EXTENDED DAY
5	8	9	100%
5	8	10	98%
5	8	11	95%
5	8	12	92%

FOR ISOLATED OR SPORADIC EXTENDED WEEKS

SCHEDULED DAYS	SCHEDULED HOURS	PRODUCTIVITY EXTENDED WEEK
6	8	98%
7	8	95%

FOR CONTINUOUS OR PROTRACTED EXTENDED WEEKS

SCHEDULED DAYS	SCHEDULED HOURS	PRODUCTIVITY EXTENDED WEEK
6	10	84%
7	10	78%

substantial confidence in the applicability of BLS values to electrical contracting which provided a more complete coverage.

Notwithstanding NECA's conclusion, it must be reiterated that on one hand the BLS data were collected under very specific conditions in the manufacturing sector and on the other hand NECA data were nothing more than a limited survey, i.e. subjective data which cannot be verified. At best, the coincidental similarity of questionable data can be considered a general indicator.

In 1969, NECA published "Overtime and Productivity in Electrical Construction"; a study conducted by the NECA Southeastern Michigan Chapter. Data are from jobs worked during 1964, presumably for electricians. The origin of the data and the work environment are unknown. Figure 9 shows the decline of productivity over periods of one to four successive weeks. What happens beyond is, as indicated, a question mark. What is striking about the four weeks of data is that weeks 2, 3 and 4 are multipliers of 1.5, 2.0 and 2.5 respectively of the first week data. This raises some serious concerns with respect to the originality of the data.

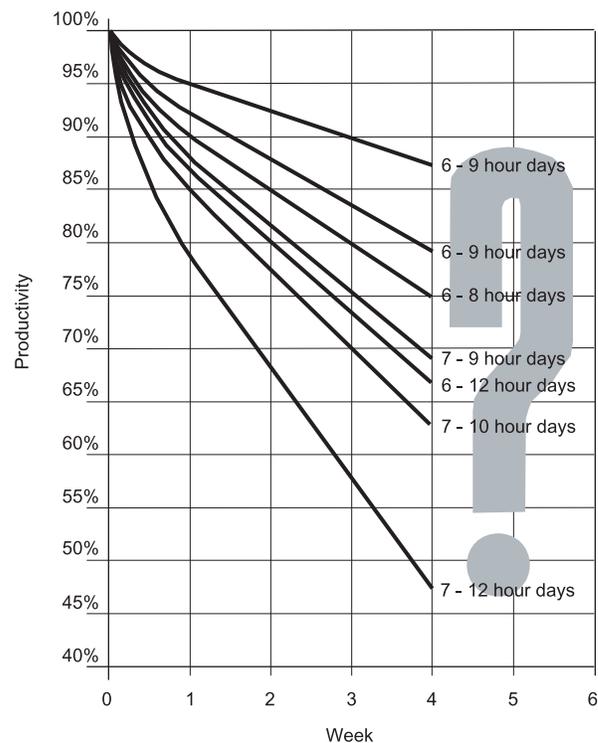


Figure 9

The findings for the number of work hours per day and the number of work days per week are depicted in Figures 10a and 10b. They are consistent with expectations.

In 1989, NECA published a second edition of "Overtime and Productivity in Electrical Construction".

The study provides information on low, average and high productivity loss for 5-, 6- and 7-day work weeks and 9, 10 and 12 hours per day for sixteen successive work weeks, based on data gathered by NECA since 1969 for journeymen electricians. The origin of the data and the work environment are unknown. Figure 11 summarizes the data for average productivity for successive weeks of overtime.

Miscellaneous Studies

In 1969 James Howerton published statistics on an overtime study conducted in 1964. The project, its location and the trades involved are unknown. Figure 12 shows productivity as a function of successive weeks of overtime.

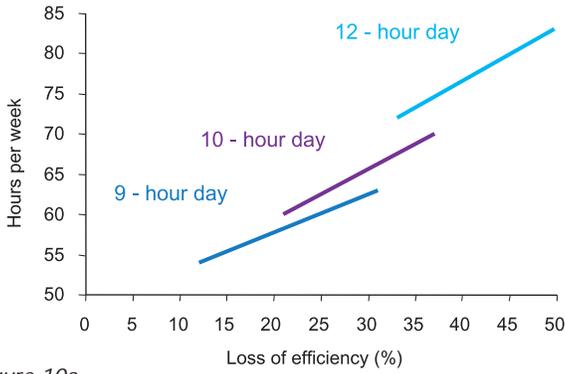


Figure 10a

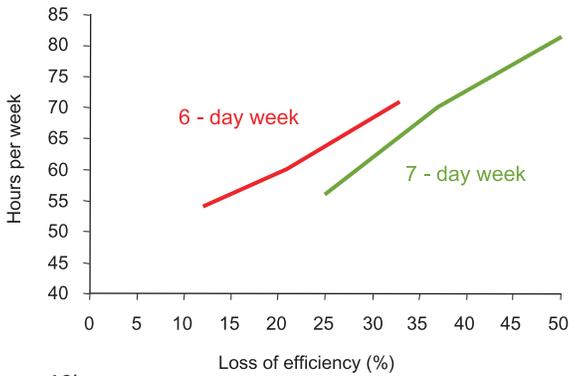


Figure 10b

In 1987 J.J. Adrian reported loss of productivity as part of an analysis of a contractor's claim. The data originate from concrete activities in Chicago in 1982. The work was performed under ideal weather conditions (60°-80°F). Figure 13 shows the **productivity losses reported for successive weeks of overtime.**

In 1991 Haneiko and Henry published statistics on the impact of overtime on concrete placement. The data were collected in 1986 on a backfit project in Texas. Overtime for concrete placement averaged 20 hours/week (60 hours/week) for an eight-week period. Productivity during this period was 35% less compared with the eight-week straight time period (40 hours/week), namely 6.78 hrs/cy vs. 5.01 hrs/cy. The only concrete work account that continued throughout the overtime period was the footings and grade beams. Straight time productivity was 4.68 hrs/cy. Figure

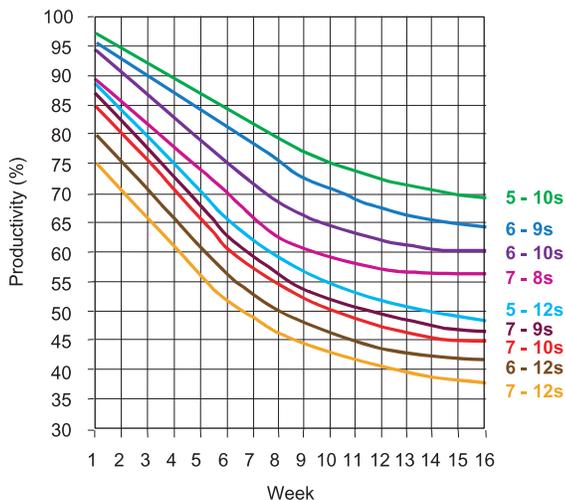


Figure 11

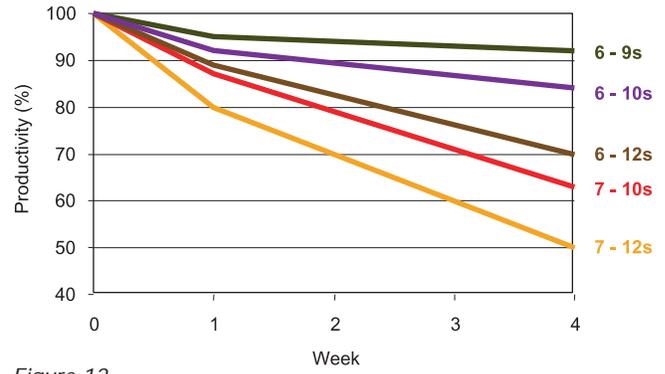


Figure 12

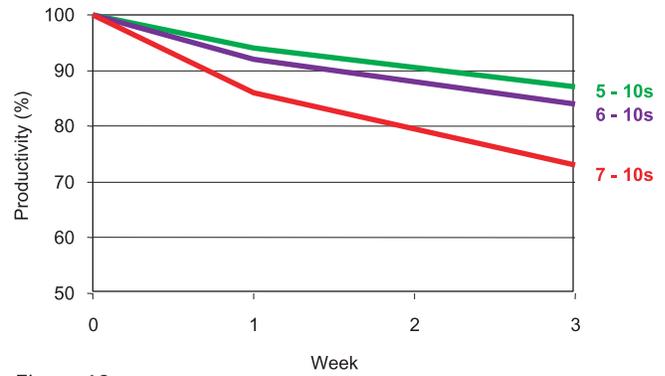


Figure 13

14 shows **productivity over eight weeks of overtime for the concrete placement of footings and grade beams.**

U.S. Army

In 1979, the Corps of Engineers published the "Modification Impact Evaluation Guide" for the purpose of evaluating impacts due to changes. With respect to overtime, the guide recognizes:

"Working more hours per day or more days per week introduces premium pay rates and efficiency losses. Workers tend to pace themselves for longer shifts and more days per week..."

When modifications make it necessary for the contractor to resort to overtime work, some of the labour costs produce no return because of inefficiency...

if overtime is necessary to accomplish modification work, the government must recognize its liability for introducing efficiency losses...

... data are included merely as information on trends rather than firm rules which might apply to any project...

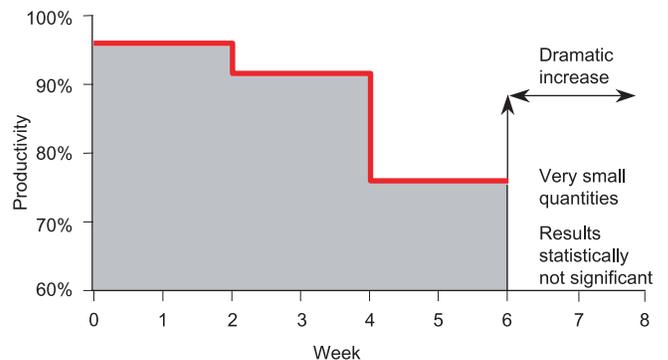


Figure 14

... data do not extend beyond the fourth week, it is assumed that the curves would flatten to a constant efficiency level."

Figure 15 depicts the curves published by the Corps on the effect of the overtime work schedule on efficiency. The origin of the data relied upon is unknown. However, it appears that the Corps accepted the NECA (1969) average data for 6-9s, 6-10s, 6-12s, 7-8s, 7-9s and 7-10s since they are identical, and added some of their own lines.

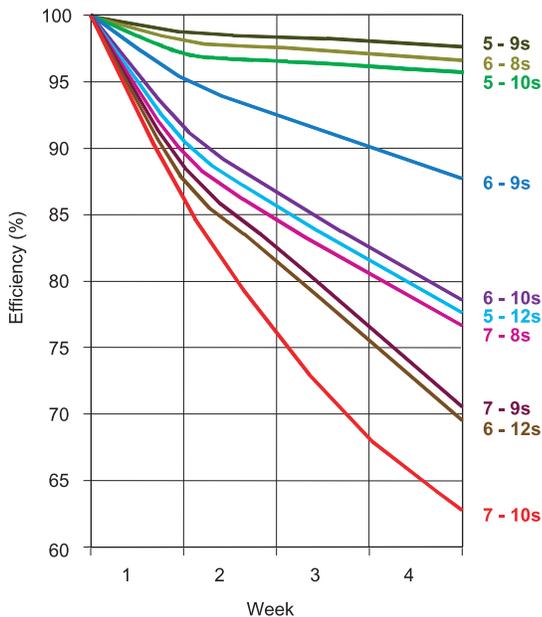


Figure 15

Synopsis

Based on the foregoing overview of available studies it is evident that only a few are based on original data. Moreover, less than reliable data have been published and republished over and over giving a false appearance of originality. Finally, data are available for a limited number of trades only. Figure 16 compares the reported efficiency from various studies for the 50-hour, 60-hour and 70-hour work weeks with the majority based on 10-hour workdays and an overtime schedule of four consecutive weeks. Subject to the qualifications already expressed, there is a certain consistency in that there is a definite, but not necessarily linear, decrease in productivity for each additional 10 hours per week.

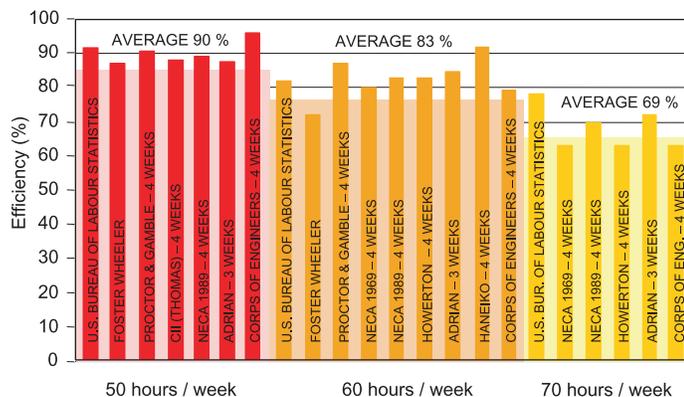


Figure 16

CONCLUSIONS

At the outset of this article it was clearly stated that published charts should only be used with the greatest caution and, more importantly, only when no other practical method is available to calculate productivity losses from the actual project records.

The inherent limitations of published charts have best been summarized by the U.S. Army Corps of Engineers:

"... data are included merely as information on trends rather than firm rules which might apply to any project."

Notwithstanding these limitations, appropriate application of published data for the purpose of forward costing of a change or accelerated schedule, i.e. before execution of the work, is considered advantageous to all parties involved. The owner will know the cost prior to embarking on a change or accelerated schedule and the contractor will get paid for the cost of the agreed upon productivity loss during the execution of the work. With this approach both parties share some risk but can avoid the costly after-the-fact dispute resolution process.

The use of published charts in an after-the-fact claim situation is more problematic. Each of the studies containing original data applies to a very specific project environment for specific trades only. It is, therefore, of the utmost importance to understand and document the surrounding circumstances of a claim situation. It is then up to the experienced analyst to compare the claim scenario to the published study which resembles it most and introduce adjustments if deemed necessary. Published data can therefore be helpful in quantifying loss of productivity in overtime situations but the result will always remain an approximation, although it may be the best one under certain circumstances.

For many types of projects no published data are available. Such projects include roadwork, pipelines, transmission lines or extensive cut and fill operations, just to name a few. However, the absence of such data is not surprising. On these types of projects contractors typically record actual quantities and hours of work, allowing for a loss of productivity calculation based on actual data. Thus, an attempt to rely on undated published data on these types of projects will invariably be treated with suspicion. Moreover, these projects are often planned from the outset with 10-hour shifts and/or 6-day week schedules to take advantage of daylight or to attract labour to remote work sites. The latter aspect is particularly relevant in cases where the labour force is housed in camps, thus eliminating daily commuting time to the work site. The fatigue resulting from a daily two-hour commute is considered similar to a daily increase of two working hours. Reliance on published charts on such type of project is therefore highly questionable.

In claim situations where the loss of productivity is a result of extended overtime and other parallel causes, none of the published charts offer any help in calculating cumulative losses. Conversely, relying on published charts for the isolation of one specific cause such as overtime may yield unreliable results. However, if there is no other practical way to calculate such loss, the analyst may have no choice but to rely on a study which best fits the project situation under scrutiny, to calculate an approximate loss.

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PAPER 2

**“Impact of Extended Overtime on
Construction Labor Productivity”
by Awad S. Hanna, Craig S Taylor, and
Kenneth T. Sullivan, 2005 ASCE Journal**

Impact of Extended Overtime on Construction Labor Productivity

Awad S. Hanna, P.E., M.ASCE¹; Craig S. Taylor²; and Kenneth T. Sullivan³

Abstract: This paper presents an analysis of the impacts of extended duration overtime on construction labor productivity. The results show a decrease in productivity as the number of hours worked per week increase and/or as project duration increases. The research focuses on labor intensive trades such as the electrical and mechanical trades. Overtime in this research is defined as the hours worked beyond the typical 40 h scheduled per week. The paper begins by presenting the effects of overtime and the need for an updated overtime productivity model. Data for the quantitative analysis was collected from 88 projects located across the United States by means of a questionnaire. Various statistical analysis techniques were performed to develop quantitative relationship curves, including multiple regression, *P*-value tests, and analysis of variance.

DOI: 10.1061/(ASCE)0733-9364(2005)131:6(734)

CE Database subject headings: Construction industry; Productivity; Scheduling; Labor relations.

Introduction

Contractors in labor intensive fields such as the mechanical or electrical trades generally allocate 33–50% of a project's total budget to labor costs (Hanna 2001). Of the typical project cost components (material, equipment, and labor), labor is considered the project element containing the most risk. The other cost components (material and equipment) are predominately determined by market price and are consequently beyond the influence of the project management. As a result, the management of labor and its productivity becomes paramount in determining the success of a project.

Commonly in construction, project durations must be compressed and work accelerated to complete the project on time or on a date sooner than originally scheduled. There are three traditional methods to accelerate a schedule: overtime, shift work, and overmanning. Overtime achieves schedule acceleration by increasing the amount of hours worked by labor beyond the typical 40 h worked per week. Past research indicated that labor productivity can be negatively impacted by overtime, causing problems such as fatigue, reduced safety, increased absenteeism, and low

morale (Horner and Talhouni 1995). Additionally, the extra work performed under the implementation of overtime comes at an increased cost, commonly time and a half. Smith (1987) indicates that the premium cost of overtime and reduced labor productivity combine so that each productive hour gained costs an average of 300% of the normal straight time hourly rate. Through the use of statistical techniques, this research will provide a quantitative relationship among overtime, project duration, and labor productivity on projects employing extended-duration overtime.

Research Objective

In today's construction industry, overtime has frequently become the planned schedule from the onset of a project. This is occurring for at least two reasons. First, with a shortage of skilled craftspeople in many parts of the country, the premium pay associated with overtime has become a necessity to attract the required workforce. Second, it has become common for business-savvy owners to request an accelerated project schedule in order to move their product to market sooner. These owners recognize the financial benefit of an early project completion despite the increased cost associated with schedule acceleration.

As overtime is used more extensively for long durations it is important for contractors and owners to understand the associated impact to labor productivity. Previous overtime studies have focused on overtime solely as a short-term schedule compression technique, and these studies can only be applied accurately to projects using overtime for a maximum of 15 continuous weeks [Construction Industry Institute (CII) 1988]. The main objective of this paper is to statistically quantify the effects of extended duration overtime in labor intensive trades. The project selection criteria, a description of the data set, and a statistical regression model are used to achieve the stated objective.

Factors Approach

Schedule acceleration results in an increase in the total work hours consumed beyond the budgeted level in order to complete

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Note. Discussion open until November 1, 2005. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on February 17, 2004; approved on September 2, 2004. This paper is part of the *Journal of Construction Engineering and Management*, Vol. 131, No. 6, June 1, 2005. ©ASCE, ISSN 0733-9364/2005/6-734-739/\$25.00.

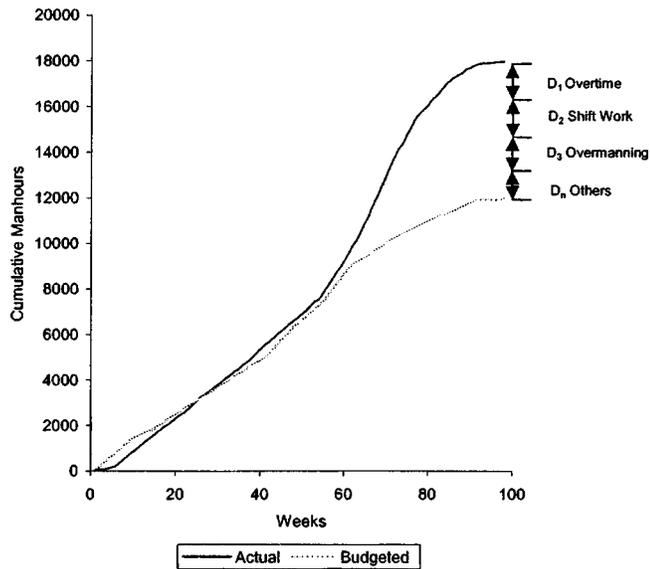


Fig. 1. Factors approach

the same amount of work originally contracted. Schedule acceleration methods, such as overtime, shift work, and overmanning, also cause a reduction in the performance of the project labor. The factors approach, as devised by Waldron (1968), stated that the cumulative impact of the various factors (overtime, shift work, etc.) on the productivity of labor equate to the total number of work hours that are consumed beyond the budgeted amount. This paper analyzes only the effects of overtime and its contributions to the work hours lost on accelerated projects. The effects of overmanning, shift work, and other impacts are not considered. Fig. 1 is a graphical representation of the factors approach as first developed by Waldron. In the figure, each factor contributes a portion of the additional hours in excess of the budgeted work hours on a project.

Definitions

For the current research, definitions of overtime and productivity are:

1. **Overtime:** Overtime is defined as the work performed over 8 h/day and 40 h/week. Overtime can occur in a variety of schedules including: 5 days of 10 h worked per day [5(10)s, 7(8)s, 6(10)s, or 7(10)s].
2. **Productivity:** Economists and accountants define productivity as the ratio between total input of resources and total output of product. Resource input includes labor, materials,

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. The latter definition is used in this paper.

Why and How Overtime Affects Labor Productivity

As a schedule compression technique, overtime is often preferred because it can produce a higher rate of progress without the coordination problems realized with shift work and the additional craftspersons needed for overmanning (Hanna 2003). However, overtime introduces additional problems including: fatigue, low morale, a higher cost per unit, a higher accident rate, and a phenomenon described by the U.S. Army of Corps of Engineers (1979) where workers tend to pace themselves for a longer day or week. The listed problems reduce labor productivity, presenting contractors with the problem of increased costs. If the acceleration is owner mandated, compensation disputes often lead to legal battles that cost both the contractor and owner substantial legal fees in addition to the argued sum.

Methodology

Data Collection

A questionnaire was developed and distributed to 500 National Electrical Contractors Association (NECA), Mechanical Contractors Association of America (MCAA), and CII member contractors. The questionnaire included two sections: a section gathering general background information about the contractor, and a section collecting specific data regarding the submitted projects. Project data collected by the questionnaire included information related to the type of construction (residential, commercial, manufacturing, industrial, etc.), specific work provided (general construction, electrical construction, mechanical construction, etc.), the budgeted and actual number of hours used on the project, the estimated and actual calendar duration, the average number of hours worked per crewmember per week, and the crew schedule used.

Additional data were collected regarding the contractor's project management experience in the industry and the contractor's size. Also collected was information concerning the project labor, the crew size, and the type of labor (union or open shop).

Table 1. Schedule Productivity Characteristics

Schedule productivity characteristics	Crew scheduling technique Days(h)			
	5(8)s	4(10)s	5(10)s	6(10)s
Median productivity index	1.00	1.05	0.93	0.79
Average productivity index	1.04	1.06	0.90	0.78
Maximum productivity index	1.33	1.25	1.30	1.00
Minimum productivity index	0.81	0.81	0.47	0.49
Standard deviation	0.14	0.089	0.21	0.17
Sample size	23	22	30	13

Table 2. Hypothesis Testing Results for Schedule Productivity Levels

Test Days(h) Days(h)	Null hypothesis	Alternative hypothesis Days(h)	<i>P</i> Value	Result
5(8)s versus 4(10)s	Same productivity	4(10)s more productivity	0.28	Same productivity
5(8)s versus 5(10)s	Same productivity	5(8)s more productivity	0.00	5(8)s more productivity
5(8)s versus 6(10)s	Same productivity	5(8)s more productivity	0.00	5(8)s more productivity
4(10)s versus 5(10)s	Same productivity	4(10)s more productivity	0.00	4(10)s more productivity
4(10)s versus 6(10)s	Same productivity	4(10)s more productivity	0.00	4(10)s more productivity
5(10)s versus 6(10)s	Same productivity	5(10)s more productivity	0.00	5(10)s more productivity

Data Characteristics

The research data were collected primarily from union specialty electrical and mechanical contractors and general contractors performing labor intensive work. The contractors were distributed across the United States. The total project databank contains 88 projects; 30 were conducted under a 5(10)s schedule, 13 under a 6(10)s schedule, 23 under a 5(8)s schedule, and 22 under a 4(10)s schedule. The projects ranged in size from 700 to over 1.4 million total work hours. The large diversity contained within the data set will allow for the final regression model to be applicable to a wide spectrum of construction projects.

Productivity Measurement

For each project in the databank a productivity index (P.I.) was used to show the ratio between the budgeted and actual labor hours expended to reach completion. The P.I. was used to show the relative labor productivity of the collected projects so that the productivity levels of the analyzed crew schedules could be compared. For the purposes of this research, the productivity index was defined as the budgeted number of work hours divided by the actual number of work hours

$$\text{P.I.} = \text{budgeted work hours/actual work hours.} \quad (1)$$

A P.I. of 1 represents a project that required exactly the number of work hours estimated to reach completion. A project that was more productive than estimated would have a productivity index greater than 1, while a P.I. less than 1 represents a project that achieved productivity levels below estimate. In general, higher P.I.s are representative of projects with greater levels of workforce productivity. Table 1 presents the productivity information for the collected projects including median, average, maximum, and minimum productivity indices, standard deviations, and sample sizes for all projects completed under each of the scheduling techniques included in this analysis.

Statistical Analysis

Upon completion of the data collection process, the data set was inspected in an attempt to draw conclusions regarding the impact of the crew scheduling techniques on labor efficiency. The methods of analysis used were: (1) hypothesis testing and (2) regression analysis. Hypothesis testing was completed in order to iden-

tify significant productivity differences between individual crew schedule types. Regression analysis was completed in order to derive an equation that could quantify the effects of weekly work hours and the actual number of project work hours consumed under a particular crew schedule on labor efficiency. The statistical tests were conducted using a pre-established level of significance of 5%.

The developed models are designed to aid in the estimation of the average productivity level for the entire period that a single crew schedule is used or, upon project completion, to determine the approximate percentage of productivity gain or loss associated with the crew schedule used. The following sections will present the development of the crew schedule productivity models.

Hypothesis Testing

Hypothesis testing was conducted to determine the significance of the productivity differences between various crew scheduling techniques. To compare the productivity levels of the four scheduling techniques included in the analysis, a series of two sample *t*-tests was conducted. The average productivity indices collected from projects completed under each crew scheduling technique were compared to those collected for every other schedule to determine if the difference in productivity levels was statistically significant. The 5(8)s and 4(10)s schedules were included in the analysis as a productivity baseline against which the overtime schedules could be measured. Consistent with previous overtime studies, the 5(10)s and 6(10)s schedules were shown to significantly reduce levels of productivity, on average compared to the standard 40 h/week schedules. In addition the 6(10)s schedule was shown to be significantly less productive than the 5(10)s schedule. Interestingly, the analysis showed no significant difference in productivity between the 5(8)s and 4(10)s schedules. Complete results of the statistical hypothesis testing can be seen in Table 2.

Statistical Model Development

Regression techniques were used to arrive at a quantitative relationship between productivity, overtime, and project size (measured by total work hours). The productivity index was denoted as

Table 3. Analysis of Variance for Overtime Regression Equation

Source	Degrees of freedom	Sum of squares	Mean square	<i>F</i>	<i>P</i>
Regression	2	1.52927	0.76464	41.81	0.000
Residual error	85	1.55436	0.01829	—	—
Total	87	3.08363	—	—	—

Table 4. Hypothesis Testing Results for Overtime Model Predictor Variables

Coefficient tested	Null hypothesis	Alternative hypothesis	<i>p</i> value	Result
Actual work hours	Equal to zero	Not equal to zero	0.000	Not equal to zero
Average hours/week	Equal to zero	Not equal to zero	0.000	Not equal to zero

the response variable and two predictor variables were established and tested to derive a model. The predictor variables and their definitions are:

Predictor Variables

1. **ActWrkHrs**=total number of actual work hours expended while using a single specified crew scheduling technique.
2. **Avg. Hrs/week**=average number of work hours per crew member per week. This value can be determined by dividing actual work hours by the average number of crew members on the jobsite each week.

Using statistical regression, a final model was developed and is given in the following equation. Table 3 contains the analysis of variance (ANOVA) information for the final model. The ANOVA table shows a more detailed calculation of the regression model. The R^2 value of the regression is 49.6%, a high value for the type of data analyzed

$$P.I. = 1.44 - 2.2E^{-7} \cdot \text{ActWrkHrs} - 0.00947 \cdot \text{Avg.Hrs/week} \quad (2)$$

The probability value (*p* value) of 0.000 for the regression's *F* ratio also affirms the model's adequacy. *t*-tests were run on the individual predictor variables to determine the statistical significance of each variable's impact on productivity. Table 4 shows the results of the *t*-tests performed on the predicted coefficients of ActWrkHrs and Avg. Hrs/Week. A low *p* value indicates that the null hypothesis should be rejected in favor of the alternative hypothesis. The tests conclude that the coefficients are statistically significant because their *p* values are lower than the pre-established level of significance of 5%.

The final model was validated through cross validation. Fourteen data points were selected at random and removed from the data set. The model was refit using 74 data points. Then, the

productivity indices of the eliminated 14 projects were estimated using the new, refitted, model. The final results of the validation can be seen in Table 5. All 14 projects are predicted within 14%, 11 project are within 10%, and five projects are within 5% of the actual productivity index.

Fig. 2 and Table 6 are graphical and tabular representations of a portion of the results of Eq. (2). In order to provide a greater level of detail, the charts have been broken down into 200,000 work hour increments. There are a total of seven sets of tables and figures representing the full range of the model's results. Fig. 2 and Table 6 are presented as examples, and the complete group of productivity tables and charts can be found in the Implementation Tool of the Construction Industry Institute research, "The effectiveness of innovative crew scheduling techniques" (Hanna 2003). The tables may be used to approximate a result of the overtime model and/or to check a calculation conducted using the model. Users must select the proper figure based on the size of the project in question. Fig. 2 represents the results of the model for projects ranging in size from 200,000 to 400,000 actual work hours.

Limitations of Model

In order to accurately apply the model the project size and weekly work hours must fall within the model limits. As with any regression equation, the overtime model is only accurate when the inputs are similar to those used in the making of the model. Therefore, the following model limits are placed on projects to which the model can be applied:

- **ActWrkHrs (700–1,414,108 work hours);** and
- **Avg.Hrs/Week (31.6–66.6 work hours)**

Additionally, for the proper use of the model a single scheduling technique must be used for all work hours (ActWrkHrs) analyzed.

Table 5. Results of Model Cross Validation

Project number	Actual Productivity index	Predicted Productivity index	Deviation
1	1.0500	1.0810	0.0310
2	1.1800	1.0713	-0.1087
3	0.9100	0.9700	0.0600
4	0.9500	1.0468	0.0968
5	0.8800	0.9872	0.1072
6	1.0000	1.0616	0.0616
7	0.9800	1.1138	0.1338
8	0.5600	0.6335	0.0735
9	1.0800	1.0714	-0.0087
10	0.7400	0.6974	-0.0426
11	0.8300	0.7696	-0.0604
12	0.7900	0.8714	0.0814
13	1.0800	1.0692	-0.0108
14	0.9100	0.9063	-0.0037

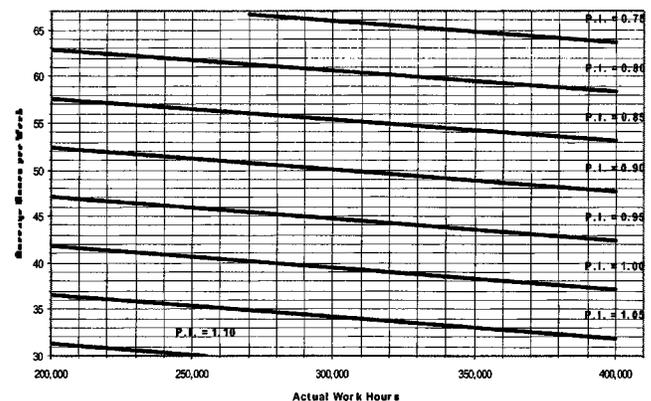
**Fig. 2.** Partial results of overtime model (200,000–400,000 actual work hours)

Table 6. Partial Results of Overtime Model (200,000–400,000 Actual Work Hours)

Actual work hours	Average hours per week							
	32	35	40	45	50	55	60	65
	Productivity Index							
200,000	1.09	1.06	1.02	0.97	0.92	0.88	0.83	0.78
210,000	1.09	1.06	1.02	0.97	0.92	0.87	0.83	0.78
220,000	1.09	1.06	1.01	0.97	0.92	0.87	0.82	0.78
230,000	1.09	1.06	1.01	0.96	0.92	0.87	0.82	0.77
240,000	1.08	1.06	1.01	0.96	0.91	0.87	0.82	0.77
250,000	1.08	1.05	1.01	0.96	0.91	0.86	0.82	0.77
260,000	1.08	1.05	1.00	0.96	0.91	0.86	0.81	0.77
270,000	1.08	1.05	1.00	0.95	0.91	0.86	0.81	0.77
280,000	1.08	1.05	1.00	0.95	0.90	0.86	0.81	0.76
290,000	1.07	1.04	1.00	0.95	0.90	0.86	0.81	0.76
300,000	1.07	1.04	1.00	0.95	0.90	0.85	0.81	0.76
310,000	1.07	1.04	0.99	0.95	0.90	0.85	0.80	0.76
320,000	1.07	1.04	0.99	0.94	0.90	0.85	0.80	0.75
330,000	1.06	1.04	0.99	0.94	0.89	0.85	0.80	0.75
340,000	1.06	1.03	0.99	0.94	0.89	0.84	0.80	0.75
350,000	1.06	1.03	0.98	0.94	0.89	0.84	0.79	0.75
360,000	1.06	1.03	0.98	0.93	0.89	0.84	0.79	0.75
370,000	1.06	1.03	0.98	0.93	0.89	0.84	0.79	0.74
380,000	1.05	1.02	0.98	0.93	0.88	0.84	0.79	0.74
390,000	1.05	1.02	0.98	0.93	0.88	0.83	0.79	0.74
400,000	1.05	1.02	0.97	0.93	0.88	0.83	0.78	0.74

This restriction applies because the projects used in the development of the regression model were conducted under a single crew schedule, so the model cannot be used to predict productivity under a combination of schedules.

Application of Model

In order to demonstrate how Eq. (2) should be used, the following scenario is presented. The example project was industrial in nature and experienced schedule compression as a result of initial engineering delays and the delayed procurement of owner-furnished items. Due to these delays the general contractor implemented overtime to complete the project as originally scheduled.

Fig. 3 shows a week by week calculation of straight time hours

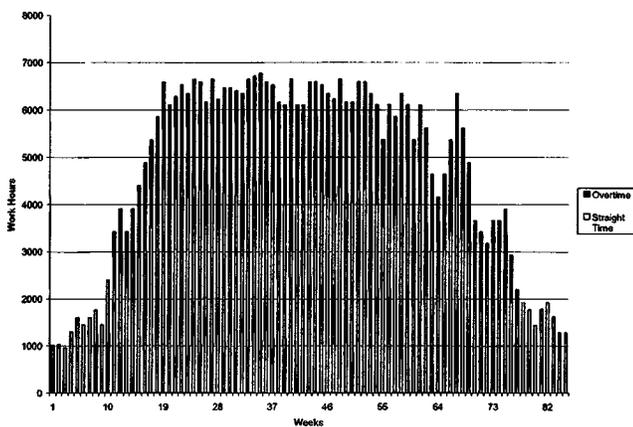


Fig. 3. Straight and overtime weekly work hours for application example project

and overtime hours worked over the course of the project. The figure shows that rigorous overtime was used on the project, primarily between Weeks 11 and 77. The project consisted of 402,059 total actual work hours worked with an original budget of 299,000 work hours, a loss of 103,059 work hours.

The model is applied only to the period between Weeks 11 and 77, when overtime was used extensively. During that 67 week period of overtime usage, 375,211 total work hours were consumed with an average workforce level of 91.8 workers/week. Solving for the average hours worked per week yields 61.0 h [$375,211 \div (67 \times 91.8) = 61.0$]. Inserting the average hours worked per week (61.0) and the total actual work hours consumed during the use of the overtime schedule (375,211) into the regression model gives a P.I. of 0.78, or a $100 - 78\% = 22\%$ loss of efficiency. Multiplying 0.22 by the total number of work hours consumed during the use of overtime gives a loss of 82,546 work hours due to overtime ($0.22 \times 375,211 = 82,546$ work hours). As a result of the 103,059 work hours that were lost during construction, 82,546 work hours can be attributed to inefficiencies caused by overtime. The remainder of the hours lost, approximately 20,513, would be due to other factors, such as the contractor's inefficiencies, stacking of trades, poor field management, and overmanning.

Benefits of Research

This study eliminates many of the problems associated with previous overtime productivity research. The validity and accuracy of past overtime studies is questioned by several authors, including Thomas and Larew. Thomas concludes that the literature on scheduled overtime is dated, based on small sample sizes, and largely developed from questionable or unknown sources (Thomas 1992). In a paper examining the reliability of past overtime

studies, Larew presented an argument that the overtime data published by Kossoris (1947), NECA (1969), the MCAA (1976), the U.S. Army Corps of Engineers (1979), and the Business Roundtable (1980) are possibly taken from one or two common sources with some manipulation of the data to make each study appear unique. Larew concludes that the published data cannot be relied upon to a reasonable degree of cost engineering certainty (Larew 1998).

The statistical productivity model produced through this study was developed from current project data in a well-documented database of 88 construction projects. The size and recent nature of the project database eliminates many of the questions of reliability raised by previous studies. Additionally, the new overtime model is broader in its application than previous studies. No previous overtime studies have analyzed the impact of extended overtime and, as a result, these studies are limited to projects using overtime for a period not exceeding 15 weeks. Many of the projects in the current database used extended overtime, which eliminated this constraint and allowed the model to be accurately applied to projects using overtime for an extended duration. This is an important improvement considering the increased frequency of using planned, extended overtime in today's construction industry.

The final statistical regression model can be used by contractors and owners to aid in their understanding of the productivity impact of extended overtime. The model can be used proactively to estimate the additional cost of labor when extended overtime is planned for a project. It can also be used reactively to determine the amount of productivity loss resulting from an unplanned period of overtime occurring during a project.

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PAPER 3

“Shift Work Impact on Construction Labor Productivity”

**by Awad S. Hanna, Chul-Ki Chang,
Kenneth T. Sullivan, and Jeffrey A. Lackney,
2005, ASCE Journal**

SHIFT WORK IMPACT ON CONSTRUCTION LABOR PRODUCTIVITY

Awad S. Hanna¹, Chul-Ki Chang², Kenneth T. Sullivan³, Jeffery A. Lackney⁴

ABSTRACT

Schedule compression or acceleration is a common problem for specialty contractors. Schedule acceleration is often the result of late start, delays and/or added work. Generally, a contractor has three options in accelerating a construction schedule; scheduled overtime, 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 cost implications or labor inefficiency associated with working a second shift. This paper quantifies 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. The productivity loss obtained from the quantification model developed through this study range from -11% to 17% depending on the length of shift work used.

KEY WORDS

Shift Work, labor Productivity, Schedule Acceleration, Schedule Compression

INTRODUCTION

Due to a multitude of reasons, project durations are often compressed and the contractor is forced to accelerate its work progress in order to accomplish a “timely” completion for the owner. When it is necessary to compress a schedule, contractors have to make a decision in selecting a method that accelerates the work 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 shift instead of single shift (multiple shift) (Noyce and Hanna 1997, Horner and Talhouni 1995, CII 1990,). There has been a

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significant amount of research conducted on scheduled overtime on construction labor productivity. However, little has been found in the literature addressing the cost implications or labor inefficiency associated with working a second shift.

PROBLEM STATEMENT

Since labor cost represents the largest portion of total construction cost, and is the most variable and risky than any other project cost components such as material and equipment those are fixed or controlled by the market price, understanding how and how much a factor affects labor productivity is crucial to improve project performance, increase profit, and maintain sound financial status of company.

Direct costs of shift work are little disputable, because they are easily tracked. The greater cause of increased project costs is labor productivity loss caused by shift work. Sometimes the unawareness of the impact of shift work leads the owner and contractor to litigation. Much effort has been made to quantify the effects of shift work on labor performance and productivity. Unfortunately, most of them are for other industries such as manufacturing, nursing, not for construction, and they fails to reach a consensus on whether shift work negatively impacts labor productivity.

RESEARCH OBJECTIVE

Through published articles and reports, the impacts of shift work on labor productivity are summarized, along with other possible causes for the productivity loss. The primary objective of this paper is to quantify the effects of shift work on labor productivity for mechanical and sheet metal contractors through statistical methods.

DEFINITION OF SHIFT WORK

Shift work is defined as the hours worked by a second group of craftsmen whose work on a project is performed after the first, or primary, work force of the same trade has retired for the day.

WHY AND HOW SHIFT WORK AFFECTS LABOR PRODUCTIVITY

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 problem 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 has also disadvantages, and introduces additional cost.

Since shift work introduces other additional cost including additional administration personnel, supervision, quality control, safety, and lighting as well as shift differential, total project cost of shift work is normally higher than that of normal operation. Colburn (1997) reported the cost of shift work to American industry was estimated in excess of \$77 billion with 84 % (64.5 billion) due to reduced human performance at work (Colburn 1997).

The 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. Additional problems associated are extensive work coordination due to little cooperation between shifts, inconsistent operating procedures across shifts, inefficient communication between crews, and the unavailability of timely administrative decision from higher management absence of management regular business hours (Penkala 1997).

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 accustomed 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). 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. 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).

Figure 1 illustrates how the 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 and outputs are simply some possible results of shift work.

QUANTIFYING THE IMPACT OF SHIFT WORK ON LABOR PRODUCTIVITY

PREVIOUS QUANTITATIVE RESEARCH

Literature review reveals more studies have been conducted in other industries, manufacturing industry (Wojtczak-Jaroszowa & Pawlowska-skyba 1967, Tilley et al. 1982, Vidacek 1986), medical service industry (Brown 1949, Totterdell et al. 1995), gas industry (Bjerner & Swensson, 1955), and transportation services (Hilderbrant et al. 1974). Since studies on shift work were made on various industries, performances were measured by various ways. Though not from construction, the data used in these studies attempts to relate the effects of shift work on human performance. The productivity loss reported by above studies ranges 3% to 52%.

Only one meaningful study (Haneiko and Henry 1991) was found in construction operation. The lack of quantitative data on construction operation is probably due to the infrequent use of shift work in construction and the perception that shift work is similar to

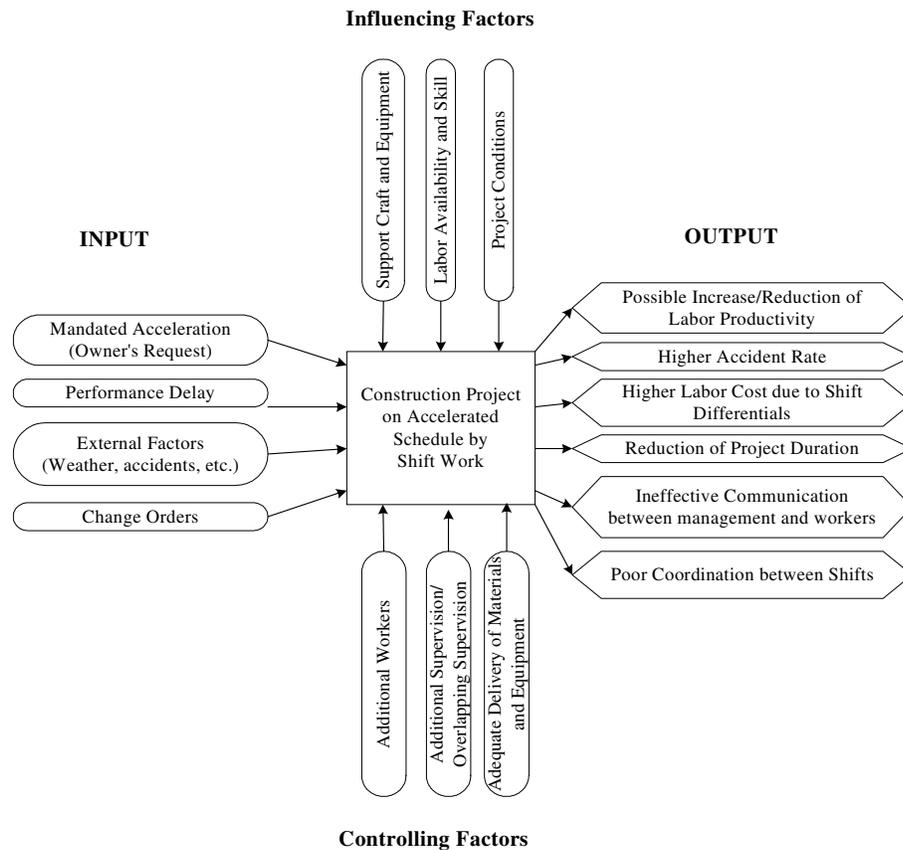


Figure 1: Schematic Structure of Shift Work (Hanna and Sullivan 2004)

overtime in its effect on productivity. Haneiko and Henry (1991) analyzing five factors hypothesized to affect construction productivity, found that double shifting has an impact on productivity. During the project, double shifting was implemented on electric work for a year. The decrease in production rate was measured to be a 24-37% depending on commodity being installed (Haneiko and Henry 1991).

As Hilderbrant's study (Hilderbrant et al. 1974), where shift work driver had a 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. Also, Cook indicated that shift work greatly affect neither absenteeism nor safety (Cook 1954). The competition between shifts might actually cause an increase in overall productivity (Horner and Talhouni 1995). Smith (1987) stated that, from company experience, 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 to 25 percent for the night shift over that of the day shift at a nuclear power plant. 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 was collected from geographically diverse specialty mechanical and sheet metal contractors. The databank contains 26 projects which experienced some amount of shift work. The sizes of the projects in terms of manhour range from 3,086 to 550,000 total manhours. Five different types of construction performed in 15 states are represented including: commercial (banks, retail, offices), industrial, institutional (hospitals, prisons), and manufacturing.

QUANTIFICATION MODEL DEVELOPMENT

EFFICIENCY LOSS

Loss of Efficiency is defined as the difference between actual hours utilized from budgeted hours including approved manhours for change orders as a percent of total actual hours utilized. Lost Efficiency may result from a contractor's low estimate, poor performance or the impact of productivity related factors. 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 (%LostEff) is defined as given in Equation 1:

$$\% \text{ Lost Efficiency} = \frac{\text{Actual Total Manhours} - (\text{Estimated Total Manhours} + \text{Approved Change Order Hours})}{\text{Actual Total Man hours}} \quad \dots(1)$$

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 (Equation 2).

$$\% \text{ Shift Work} = \frac{\text{Total Shift Work Manhours}}{\text{Budgeted Total Man hours}} \quad \dots (2)$$

The greater the value of the ratio, the more shift work that 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. The collected data possessed ratio limits of 0.01 and 0.53 for shift hours worked over the budgeted total hours work.

STATISTICAL MODEL DEVELOPMENT

Regression analysis was performed to develop a quantitative relationship between lost productivity (Percent Lost Efficiency) and shift work (Shift Work Hours over Total Hours) with denoting Percent Lost Efficiency (formulated in decimal, not percentage form) as the response variable and %SW as predictor. The final model is given as equation 3. Figure 2 is a graphical representation of equation 3. Tables 2 and 3 contain the statistical analysis of the final model.

$$\text{Productivity Loss} = 0.22052 + 0.07152 \text{ Ln} (\% \text{Shift Work}) \quad \dots\dots (3)$$

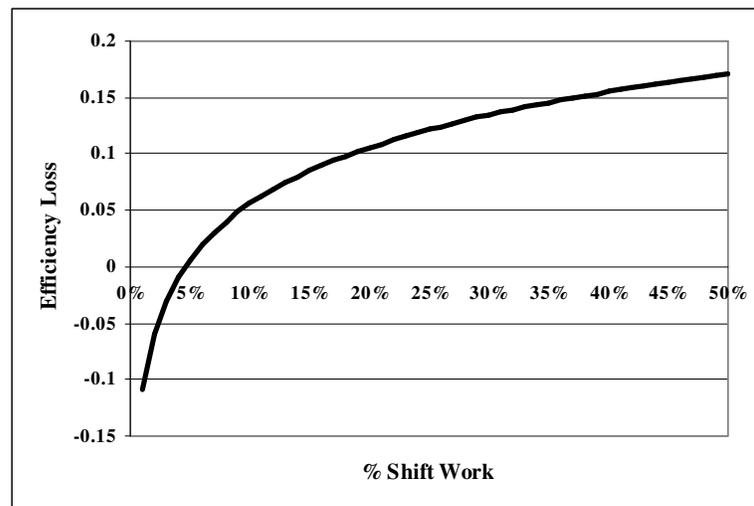


Figure 2: Effects of Shift Work on Labor productivity

Table 2: Analysis of Variance for Shift work Regression Equation

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	P
Regression	1	0.51263	0.51263	22.83	0.000
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	0.000	Not equal to Zero

SCOPE OF THE MODEL

The applicable range of the model given in Equation 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 ranges of 3,000 to 550,000 total manhours. The range of % Shift Work is between 0.01 and 0.53. If an electrical, mechanical or sheet metal project is within these values, Equation 3 can be implemented to determine the impact of shift work on labor productivity.

COMPARISON TO PREVIOUS STUDIES

Direct comparison to previous studies is difficult due to different industry contexts, type of work and investigated workers, and 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 obtained from the quantification model developed through this study ranges -11% to 17% for the amount of shift work from 1% to 50% of budgeted total manhours; lower than the results of two studies done before 1950's. Since the data used for these two studies are outdated, more meaningful comparison was drawn with studies done after 1960's. The study results on productivity loss reported after 1960's are 2.86% and 9.26% (Wojtczak-Jaroszowa & Pawlowska-skyba 1967), -10 % (Hilderbrant et al. 1974), 7~9% (Tilley et al. 1982), 10% (Walden 1986), and 4.5% (Vidacek 1986). All of these are quite identical with efficiency loss as defined by Equation 3.

Haneiko and Henry (1991) found that the implementation of a second shift reduced overall productivity by 24-38%; somewhat higher than the result of this study. Two possible reasons for this difference are: (a) an exact equivalent measure cannot be given due to the lack of data provided by Haneiko and Henry, and (b) the productivity loss might come from the use of combination of shift work and overtime rather than solely from shift work, judging from their study result showing the impact of double shifting on productivity varied overtime. Haring claimed a 20 to 25% saving 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 Equation 3 yields 11% saving of productivity, slightly lower than the findings reported by Haring, but have same direction.

VALIDATION

The final model was validated through cross-validation method. In cross validation, the collected data is randomly segmented into five subgroups. The model was refit using four subsets, and then the remaining 20% of the data is then used to predict the model's accuracy and precision. This process was repeated for all the five subsets. The result indicates that the equation appears to be more accurate for the project experiencing small amount of productivity loss; less than 20% of productivity loss, due most likely from project conditions or contractor's ability to manage the project.

SUCCESSFUL APPLICATION OF SHIFT WORK

Several contacts with industry professionals during this research revealed some techniques to reduce productivity losses and improve the performance of labor during shift work.

- **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

hours longer and the foreman of the second shift to arrive 1 –2 hours earlier.

- **Selection of work assigned to a second shift** – By 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 not requiring much engineering and design support, relatively small scope of work. 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.

LIMIT OF STUDY

The quantitative part of this study is limited to mechanical and sheet metal projects with lump sum contracts and a traditional project delivery system. However, the quantitative data can be expanded to other labor intensive project.

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 use of Equation developed in this research, contractors have the ability to determine the effect shift work had on the productivity of the labor during the hours where shift work was employed. Use of this equation can also serve as a beginning to negotiations between owners and contractors for adjustments for owner initiated schedule acceleration. 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.

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PAPER 4

**“Scheduled Overtime Effect on Construction Projects”
Business Roundtable Report C-2,
November 1980**

The Business Roundtable

Report C-2
November 1980

**SCHEDULED OVERTIME
EFFECT ON
CONSTRUCTION PROJECTS**

November, 1980
A Construction Industry Cost Effectiveness Task Force Report

Executive Summary

This paper reviews an analysis of the impact of scheduled overtime operation on construction projects and the inflationary effects of such operations. The data and findings cited in the previous Business Roundtable report (1974) on this subject have been found still valid and support the following conclusions:

- Placing field construction operations on a project on a scheduled overtime basis disrupts the economy of the affected area, magnifies any apparent labor shortage, reduces labor productivity, and creates excessive inflation of construction labor costs without material benefit to the completion schedule.
- Where a work schedule of 60 or more hours per week is continued longer than about two months, the cumulative effect of decreased productivity will cause a delay in the completion date beyond that which could have been realized with the same crew size on a 40-hour week.
- Where overtime operations are deemed necessary despite productivity losses—for example, on remote construction projects where bachelor housing is provided at the job site and on maintenance turnarounds—proper management can minimize the inflationary effects. Management actions to be considered include use of an additional shift and periodic shutdown of the work for a Sunday or weekend.

General Background

In most manufacturing operations, the output of completed units per hour of labor input is fairly easy to document and provides a sound basis for establishing the productivity of labor. This is not the case in construction work. In the construction

industry generally, there is no fixed standard of comparison for documenting productivity.

The data used for the conclusions reached in this report are based on fixed standards of measuring work hours required to perform specific functions necessary to accomplish construction operations. For example, the fabrication of any section of pipe involves handling, cutting, bevelling, bending, and welding or threading. Standard work hour requirements for each function provide a base for comparison with actual work hour expenditures and provide good documentation of productivity.

Synopsis of Source Data

This paper relates only to operations where the total job is placed on an overtime basis for an extended period of time. Meaningful data to cover periodic overtime is not available.

There have only been a few studies made of the effect of labor hours on labor efficiency (which is defined as changes in output resulting solely from labor input). This is particularly true in the construction industry. Very little data beyond 70 hours per week is available for studying the effect of overtime on the unit cost of labor in the construction crafts.

From studies of morale and fatigue factors as affected by working hours,¹ the following conclusions have been reached:

- Whatever the reason, one fact stands out clearly: The longer the hours, the more scheduled work time is lost through absenteeism.

- Injuries increased as hours increased, not only in absolute numbers, but also in the rate of incidence.
- For hours above eight per day and 48 per week, it usually took three hours of work to produce two additional hours of output when the work was light. For heavy work, it took two hours to produce one hour of additional output.

HOURS OF WORK PER DAY

Comparative Studies

Most comparative studies regarding the variation of productive output under varying hours of work have been made on manufacturing operations where the manual functions are somewhat paced by automated processes. In construction work, automated operations seldom exist, and the harmful effects of overtime operations should be more severe.

Another study² concluded that four weeks of eight hours per day was found to be 16 percent more efficient than four weeks of nine hours per day. This study was based on the *total cost* of finished products manufactured by the identical process under the two different hours per day of work time.

A study of the productive output of labor in completed units resulted in the following statistics for carpenters:

8-hour day	Completed units	120 pieces per hour.
9-hour day	Completed units	100 pieces per hour.

This indicates a worker is 20 percent more productive for four weeks at an eight-hour day than for four weeks at a nine-hour day.

DAYS OF WORK PER WEEK

When operations are scheduled on a seven-day basis, management action can materially affect labor productivity. A study² made at one factory showed that a substantially higher output resulted during the week following an “off Sunday” than the week following a “work Sunday”

EFFECTS OF OVERTIME ON CONSTRUCTION WORKERS

The studies referenced above were based on observations for relatively short durations of four weeks or less. The construction studies discussed below are based on longer periods of time.

When a project in an area is placed on a scheduled overtime basis, the movement of workers from other projects in the area to the overtime job creates an "auction" atmosphere. Other jobs go to overtime to hold their labor, and a bidding process is established. The local labor supply is fairly constant, and the additional productive capacity of transient workers is offset by the reduced productivity of all workers on an overtime schedule. Usually, a major portion of the increase in numbers of workers in the affected area is a result of permit workers in the crafts who are less proficient or poorly qualified.

Disruptions created by unwilling or poorly qualified craft workers, longer working hours each week, increased absenteeism, and reduced effectiveness due to fatigue reduce the productive output of labor materially. On extended overtime, the reduced productivity of workers for a week's work is equal to or greater than the number of overtime hours worked.

EFFECTS ON COSTS

The premium cost for overtime hours, plus the loss in productivity for the total hours worked, results in an unreasonable inflation of the unit labor cost. The charts included in this study illustrate the effect of scheduled overtime on unit labor cost and labor productivity. There is no precise conclusion regarding the cost of overtime that is universally applicable. Time, local labor climate, management actions, and job location are all factors which affect the cost of overtime operations.

OVERTIME VS. PRODUCTIVITY

Within narrow limits, workmen expend energy at an accepted pace established by long periods of adaptation. When the hours of work per day or per week are changed, there is an adjustment period. Studies reveal that scheduled overtime operations result in a sharp drop in productivity initially, followed by a fairly substantial recovery by the end of the first week. The recovery level of productivity may then hold fairly steady for a period of two to three weeks but show a steady decline for the following two to three weeks. After five to six weeks of operations, there is a further drop in productivity which levels out at a low point after nine to twelve weeks of sustained overtime operation. It should be understood that this condition results from normal reactions and does not reflect the effect of other adverse factors such as labor, climate, and poor management

SURVEY RESULTS: NATIONAL CONSTRUCTORS ASSOCIATION

A survey in the late 1960's by members of the National Constructors' Association for the scheduled overtime Task Force covered 60 percent of their total membership and showed that 23 percent of their contracts worked on a scheduled overtime basis. They also reported that 20 percent of their dollar volume of construction was on an overtime basis. This indicated that 20 percent of a \$2.8 billion labor cost was expended on an overtime schedule representing \$560,000,000 of labor payroll.

The survey showed that 66 percent of the overtime schedules were established for the purpose of attracting labor; the remaining 34 percent were to maintain or accelerate construction schedules.

The number of hours per week varied from job to job, but 50 hours represented a conservative average. At 50 hours per week, the inflationary effect on construction labor cost was 60 percent of the cost on a normal 40-hour week. This indicated that the same volume of industrial construction could have been accomplished for \$340,000,000 of labor cost if there had been no overtime involved. The added \$220,000,000 represented inflation of construction labor cost for only this segment of construction.

While the amount of work performed on overtime schedules has not been surveyed recently, it is estimated that the 20 percent figure has been reduced by about half. This is largely a result of increased awareness of the detrimental effects. However, there still is considerable potential for improvement.

CIRCUMSTANCES WHERE OVERTIME SCHEDULES ARE SOMETIMES EMPLOYED

As stated earlier, the analysis of productivity and cost effects of overtime operations in this paper are based on construction projects where full overtime schedules are employed for an extended period of time. It is further assumed that the construction workers commute to work daily.

Construction work is sometimes performed in special circumstances in which owners and contractors have felt that overtime schedules are justified despite the detrimental effects on productivity and cost.

Work in Remote Areas

Some construction job sites are located such that daily commuting of the construction worker is impractical, and he must obtain, or be provided, temporary quarters away from his family, at or near the job site. The higher weekly earnings resulting from an overtime schedule are sometimes employed to attract workers in these circumstances.

Some observers feel that the absence of a daily commute (where workers are housed and fed near the work) decreases the fatigue factor and the resulting productivity decline on an overtime schedule.

Work Requiring Shutdown of Production Facilities

In other circumstances, extended hours work schedules may be employed because operation of existing production facilities must be discontinued during the construction. This may involve emergency rebuilding following storm or fire damage, or construction/renovation work which must be done in conjunction with a maintenance turnaround or other outage. Owners in such circumstances may conclude that the high cost of downtime justifies the inefficiencies of overtime scheduling.

MANAGEMENT ACTIONS TO DECREASE PRODUCTIVITY LOSSES

Where work in excess of 40 hours per week is necessary, there are a variety of alternative or remedial actions which should be considered by management, depending on the circumstances:

- Use of travel or subsistence payments as an alternative to additional hours of work to provide sufficient total compensation to attract workers to remote sites.
- Employment of additional shifts—two or three shifts are often more productive than extended overtime.
- Use of an additional crew to provide scheduled time off without work interruption (e.g., each man works 14 days, then off seven days, as is common on offshore platform work).

- Where work is scheduled seven days/week, periodic shutdown of the work over a Sunday or weekend—productivity benefits may more than offset the lost working time. (Figure 8 illustrates the effect of this on a project on a 70 hours/week schedule.)
- An innovative approach is being applied to achieve seven days/week, 10 hours/day work on a nuclear power plant project. Premium pay is minimized by use of two alternating crews, each working four 10-hour days followed by four days off. The impact of costs and productivity will be analyzed when the project is completed and all data has been received.

ILLUSTRATIONS

Figures 1 through 8 illustrate the effects of overtime in the construction industry on costs and productivity.

FIGURE 1.
Effect of Premium Pay for Overtime on Cost of Labor

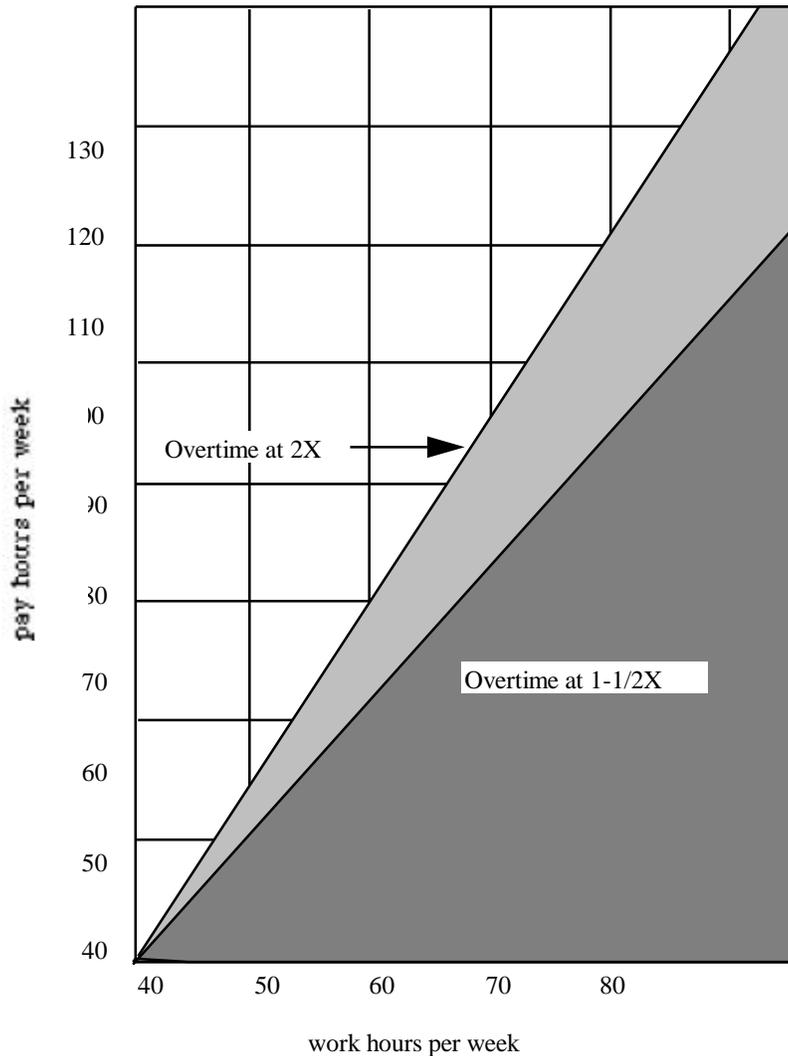


Figure 1 illustrates the effect on payroll cost when construction projects are operated on an overtime basis. The upper line applies where the craft working agreements stipulate double time pay for all overtime. For 60 hours of scheduled work, the worker will be paid for 80 hours. The additional 20 hours of pay is a premium only and represents a $33\frac{1}{3}$ percent inflation of construction wages per hour of scheduled work time.

Many labor agreements now provide for Mon.—Fri. overtime (or a portion of it) @ $1\frac{1}{2}x$. In such cases, the pay effect lies between the two lines.

FIGURE 2
Cumulative Effect of Overtime on Productivity 50 and 60 Hour Workweeks

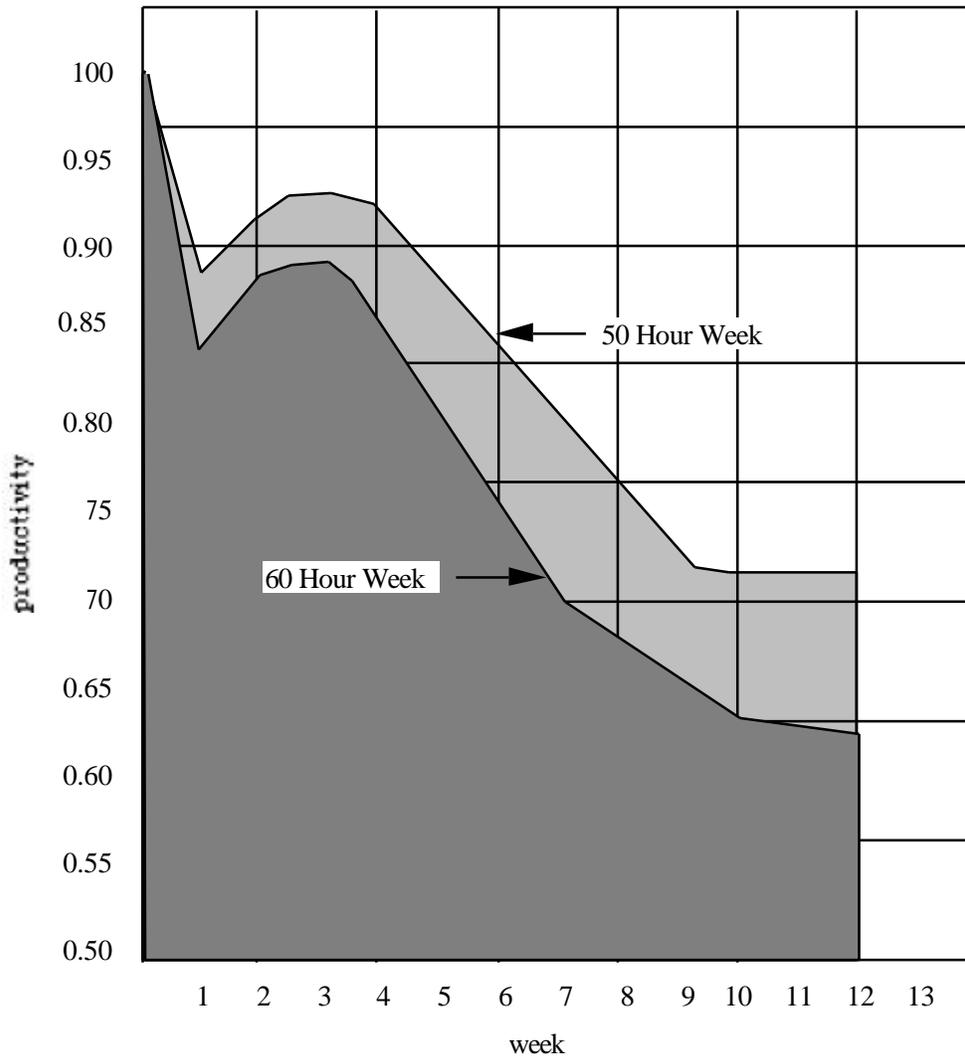


Figure 2 represents the reduction in productivity normally experienced on projects operated on a basis of 50 hours per week and 60 hours per week. The data for these curves is from project operations in an area of tranquil labor relations and with excellent field management direction. The measure of productivity is a comparison of actual work hours expended for preplanned operations with a fixed standard base of calculated work hour requirements called a "bogey." These observations are on a weekly basis with all completed work recorded from physical count or measurement and the work hours expended obtained from actual payroll hours. The curves reflect the averages of many observations.

FIGURE 3 Cumulative Cost of Overtime—Successive Weeks Productivity Loss Plus Overtime Premiums

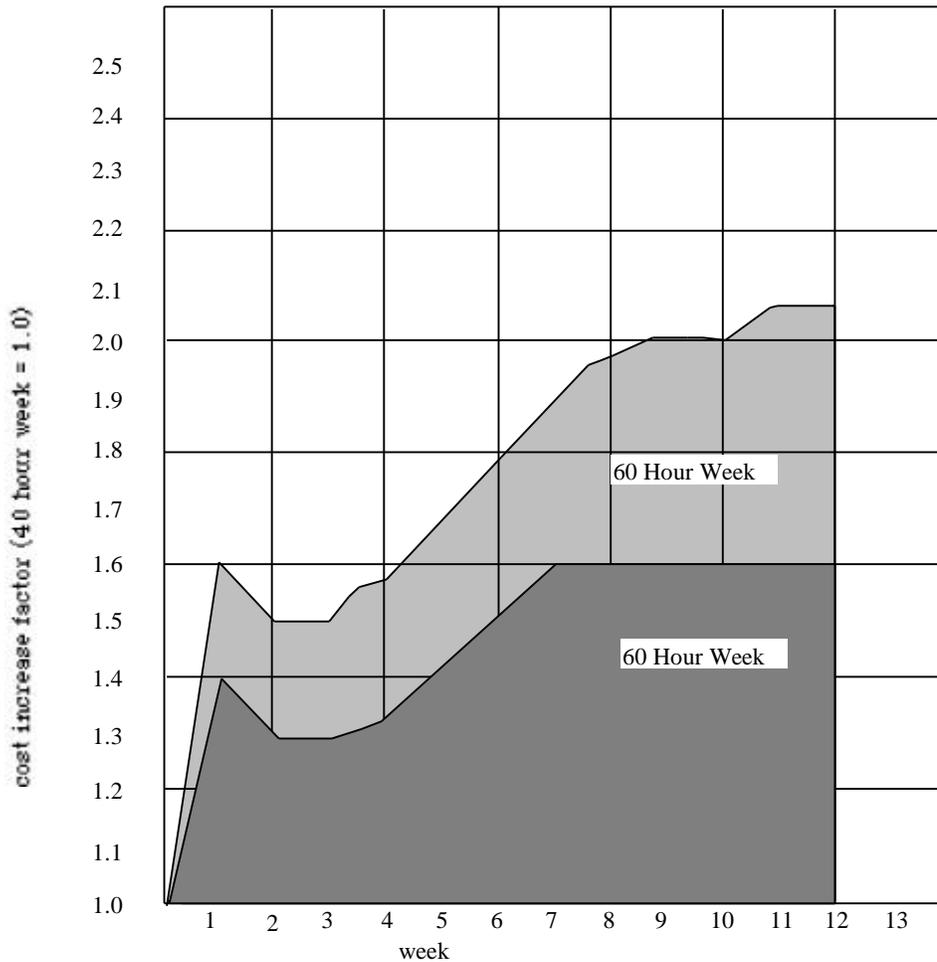


Figure 3 shows the cumulative effect of scheduled overtime operation on the unit labor cost of construction for 50 and 60 hours per week. This data includes the effects of both reduced productivity and double-time pay for overtime hours. The cost increase factor is the ratio of pay hours to work hours divided by the productivity factor (shown in Fig. 2). For 50 hours per week of scheduled operations, the unit labor cost of construction will increase by approximately 60 percent after about seven weeks of operation. For a scheduled operation of 60 hours per week, the unit labor cost will increase by 100 percent to 105 percent after approximately eight weeks of operation.

If all overtime were at $1\frac{1}{2}x$ instead of $2x$, the unit labor cost would still increase by over 80 percent after eight weeks at a 60 hours per week operation.

FIGURE 4. Relationships of Hours Worked, Productivity and Costs (40 Hours vs. 50 Hours)

1 50 Hour Overtime Work Weeks	2 3 Productivity Rate		4 Actual Hour Output for 50 hr. Week	5 Hour Gain Over 40 hr. Week	6 Hour Loss Due to Productivity Drop	7 Premium Hours	8 Hour Cost of Overtime Operation (at 2X)
	40 Hr. Week	50 Hr. Week					
0-1-2	1.00	.926	46.3	6.3	3.7	10.0	13.7
2-3-4		.90	45.0	5.0	5.0	10.0	15.0
4-5-6		.87	43.5	3.5	6.5	10.0	16.5
6-7-8		.80	40.0	0.0	10.0	10.0	20.0
8-9-10		.752	37.6	-2.4	12.4	10.0	22.4
>10		.750	37.5	-2.5	12.5	10.0	22.5

Figure 4 shows the effect of reduced efficiency of a 50 hour week and the premium cost of overtime. When a job is scheduled for 50 hours per week, there is a reduction in productivity for the total 50 hours—not just for the 10 hours of overtime. Column 3 reflects an interpretation of the productivity rate from Figure 2 for the periods shown in Column 1. Column 4 reflects the return in productive work for 50 hours of scheduled operations, due to the reduction in productivity. Column 5 shows the productive effort gained for the week over 40 hours due to the overtime hours worked. Column 8 shows the cost of this gain. It is interesting to note that after working overtime for six to eight weeks, labor cost is inflated by 50 percent with the productive returns no greater than would be accomplished on a 40-hour week. Records indicate that continuous overtime operations beyond eight weeks results in an actual productive return of less work accomplishment than a regular 40-hour week Figure 5 shows the same data for a job scheduled for 60 hours per week.

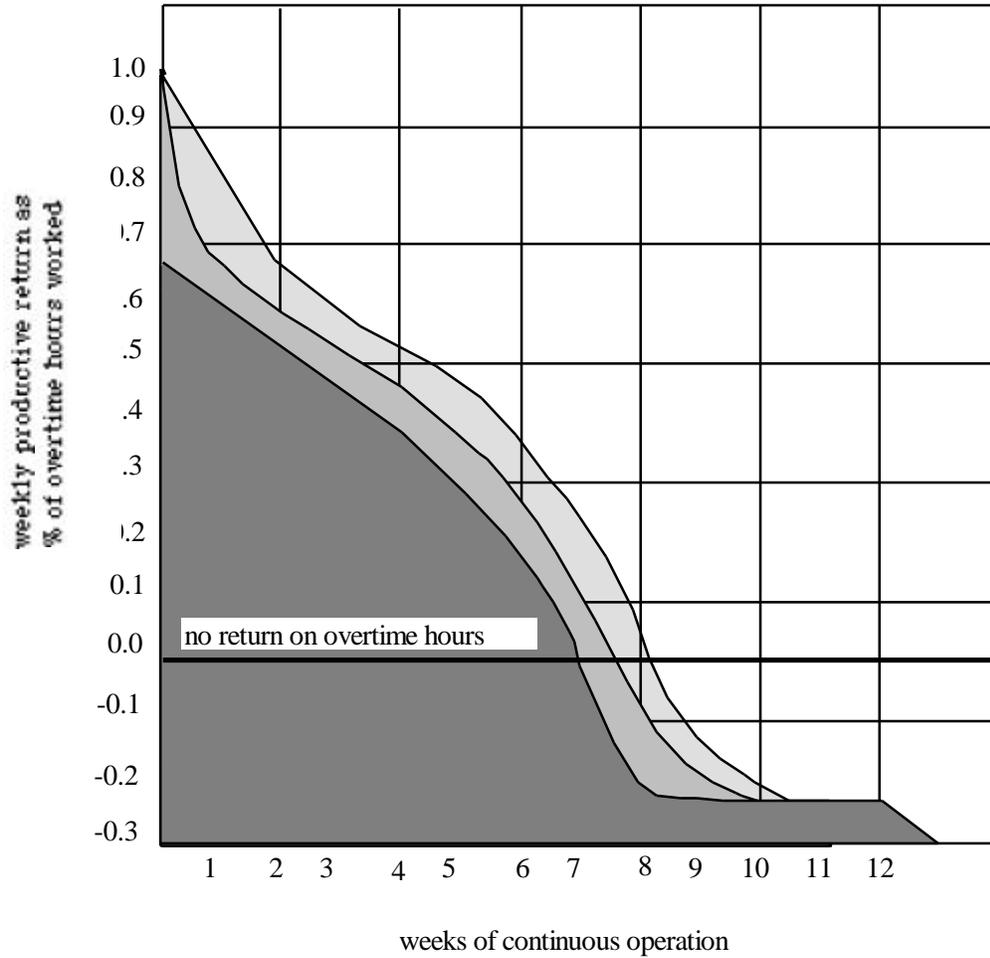
FIGURE 5
Relationships of Hours Worked, Productivity and Costs
(40 Hours vs. 60 Hours)

1 60 Hour Overtime Work Weeks	2 3 Productivity Rate		4 Actual Hour Output for 60 hr. Week	5 Hour Gain Over 40 hr. Week	6 Hour Loss Due to Productivity Drop	7 Premium Hours	8 Hour Cost of Overtime Operation (at 2X)
	40 Hr. Week	60 Hr. Week					
0-1-2	1.00	.90	54.0	14.0	6.0	20.0	26.0
2-3-4		.86	51.6	11.6	8.4	20.0	28.4
4-5-6		.80	48.0	8.0	12.0	20.0	32.0
6-7-8		.71	42.6	2.6	17.4	20.0	37.4
8-9-10		.66	39.6	-.04	20.4	20.0	40.4

Figure 5 is the same as Figure 4 except the data is for a 60 hour week.

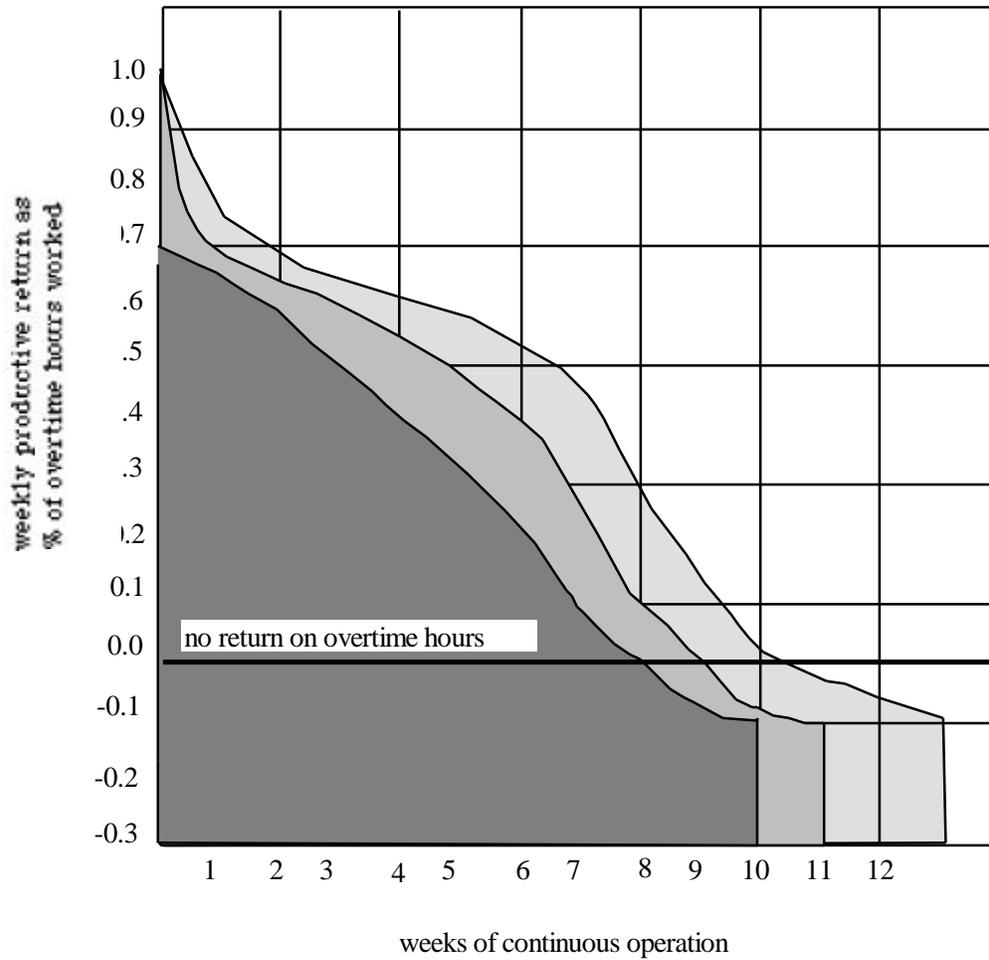
It is important to note that the effect of reduced labor productivity reaches the point of no productive returns on overtime hours earlier for a 50-hour schedule than for a 60-hour schedule. However, the inflated cost per hour of productive effort is greater for the 60-hour schedule. This results from the reduced productivity applying to a smaller base of overtime hours and indicates that a 45-hour job schedule very quickly becomes nothing more than wage inflation.

FIGURE 6
Ratio of Productive Return to Overtime hours for 50 Hour Job Schedule



Figures 6 and 7 are graphs reflecting the ratios of productive return to overtime hours for long-term job schedules of overtime operations. Obviously, one curve would not be representative of all jobs, but the three curves reflect the average and the range of expected performance.

FIGURE 7.
Ratio of Productive Return to Overtime Hours for 60 Hour Job Schedule



Direct comparisons of various data are difficult since all measurement of productive effort is not referenced to a Fixed Standard. The industrial firm's data on productivity is based on Fixed Standards, and a performance of 1.0 may not be the same as a performance of 1.0 referenced to some other standard of comparison. As a result, a 30 percent reduction of productivity in one set of data could compare with a 15 percent reduction reflected in another set of data due to this difference.

FIGURE 8 Performance Curve — #4 shutdown

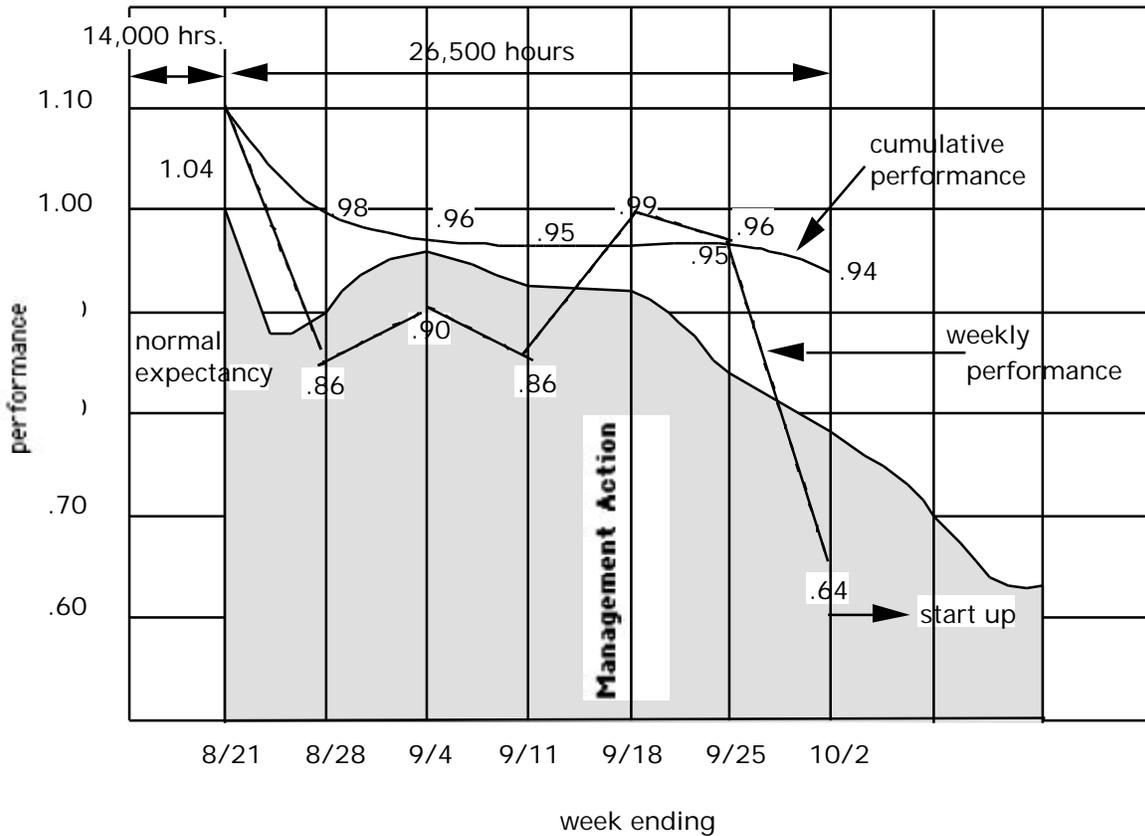


Figure 8 is a graph of actual records for a project operating on a 70-hour per week schedule for a period of seven weeks. The seventh week involved commissioning and start-up operations, and effective performance measurement was not practical.

Prior to the week ending 8/21, 14,000 hours of work had been accomplished on a regular schedule of 40 hours per week. The labor performance for the week ending 8/21 was 1.10, which is a performance 10 percent better than the bogey standard. The bogey standard is a tight target of work hour requirements for various functions and represents good performance. It is, however, an attainable target and is not an industrial engineering ideal.

The solid line marked "cumulative performance" is the cumulative labor performance for the total job to date and on 8/21 was 1.04. The dramatic improvement in weekly performance from 0.86 on 9/11 to 0.99 on 9/18 was the result of a management decision to shut down all construction operations on the Sunday preceding the 9/18 report.

The line marked normal expectancy represents the field management's prediction of expected performance for the overtime operation. It is significant to understand that this job of seven weeks' duration was an emergency turnaround type of operation of relatively short duration. The total construction activity of this job extended over several years and was never operated on an overtime basis for the total job.

Selected References of Studies Related to Overtime Costs

- 1 Bronha, Lucien: "Physiology in Industry," Pergammon Press, Toronto, 1960.
2. Dankert, Mann and Northrup: "Hours of Work," Harper and Row, New York, 1965.
3. Department of Labor Bulletin No. 917 (B.L.S.) GPO Washington, DC, May 1947.
4. Kossoris, Max: "Studies of the Effects of Long Working Hours," B.L.S. Bulletins 791 and 791 A, GPO Washington, DC, 1944.
5. Mechanical Contractors' Association of America, "How Much Does Overtime Really Cost?" Bulletin 18-A, 1969.
6. National Electrical Contractors' Association: "The Hidden Cost of Overtime," Detroit, 1969.
7. Northrup and Brinberg: "Economics of the Work Week," National Industrial Conference Board, New York, NY, 1950.
8. Princeton University Industrial Relations Digest XII "Fatigue and Productivity," Princeton, NJ, September, 1942.

¹¹ Dept. of Labor Bulletin No. 917: "Hours of Work & Output." Washington. D C 1947

²² "Use of Statistics In the Investigation of Industrial Fatigue", Phillip Sargent Florence, Columbia University,. 1918

PAPER 5

**“Effects of Scheduled Overtime on Labor Productivity”
by H. Randolph Thomas, 1992**



EFFECTS OF SCHEDULED OVERTIME ON LABOR PRODUCTIVITY

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Note. Discussion open until August 1, 1992. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on January 11, 1991. This paper is part of the *Journal of Construction Engineering and Management*, Vol. 118, No. 1, March, 1992. (DASCE, ISSN 0733-9364/92/0001-0060/\$1.00 + \$.15 per page. Paper No. 1241.

ABSTRACT: This paper reviews the construction literature on the effects on labor productivity of scheduled overtime. The literature is organized into three groups: studies based on data from project records, studies in which the sources of data are unknown, and studies done in the manufacturing sector. Analyses are also performed on the influence of the number of days per week and the number of hours per day. The literature on scheduled overtime was found to be very sparse; dated to the late 1960s and earlier; based on small sample sizes; and largely developed from questionable or unknown sources. The analysis reveals very few original data. Many studies reference other studies, giving the false appearance of originality. The analysis of data shows general consistency with respect to overall losses of efficiency. However, with respect to the loss of efficiency as a function of the number of hours per day and the number of days per week, many studies show that the effect of these two variables is negligible. The paper concludes that these studies provide strange and largely unbelievable results.

INTRODUCTION

Construction overtime has frequently been used as an inducement to attract labor and to accelerate schedule performance. Although there may be positive short-term benefits to working an overtime schedule, the long-term consequences are typically viewed as detrimental. Understanding the effects of overtime scheduling is quite difficult because the factors affecting productivity in the overtime situation are numerous. Furthermore, if an overtime schedule must be used, there is little, if any, information available to aid in deciding which type of schedule to adopt (Thomas 1990).

Reliable studies of the effects of extended overtime on labor productivity are very difficult to produce because there are many factors that can affect productivity, some of which have nothing to do with the overtime situation. Examples include the character of work being performed and start-up and testing activities. While obvious, it is often forgotten that manpower is not the only resource or component that is consumed at an accelerated pace in an overtime situation. Materials are installed at a faster rate; consumables, tools, and construction equipment are in greater demand; and engineering questions and information demands must be processed at a faster rate. Absenteeism, accidents, and fatigue may become a growing problem, and the quality of workmanship may decline. Thus, if a project is behind schedule,

working overtime may simply exacerbate the problem. Therefore, whenever overtime is discussed, the surrounding circumstances must be clearly understood.

OBJECTIVE

The objective of this paper is to critique the literature describing the effects of an overtime schedule on construction-labor productivity. The need for such a summary arises because, relative to the amount of published literature, little is known about the origin of the overtime data, number and type of projects, and surrounding circumstances. Yet widespread assumptions have been made that the data and conclusions are reliable. This paper clarifies the aforementioned aspects for each data set.

SCOPE

This paper focuses on scheduled or extended overtime, that is, an overtime schedule that lasts longer than several weeks. Spot overtime, which is intermittent, is not covered, because the negative aspects are minor relative to the job as a whole.

The literature was collected from published and unpublished sources. The graphs are presented to illustrate the flaws in the data and should not be interpreted as validating or invalidating the effects of scheduled overtime on labor productivity.

DEFINITIONS

In this paper, the following definitions are used:

"Extended overtime" is involved in a work schedule that extends over more than 40 hr of work per week. The schedule is planned in advance and lasts for at least three consecutive weeks, and typically longer. The term "overtime" is used interchangeably with "extended overtime."

"Labor productivity" is the ratio of the input in terms of labor hours to the output in terms of units of work.

STUDIES OF HOURS PER WEEK AND HOURS PER DAY

Various studies have reported losses of productivity caused by scheduled overtime. These studies are grouped in the following according to the source of the data and the applicability to construction situations.

Data from Project Records

An extensive review of the published literature and other sources yielded three studies of the effects of construction overtime in which the project records were the basis for the conclusions. Table 1 summarizes pertinent data about each study.

TABLE 1. Summary Data on Overtime Studies Based on Project Records

Source (1)	Time frame (2)	Number of projects (3)	Location of projects (4)	Project type (5)	Craft (6)
Proctor & Gamble ^a	1960s	1	Green Bay, Wisc.	Process plant	Unknown
Foster Wheeler ^b	1963-68	5	Ohio Valley	Fossil boilers	Boilermakers
Construction Industry Institute (CII) ^c	1984-88	7	La., Mo., Tex., Wyo.	Process and power plant	Carpenters, electricians, insulators, ironworkers, laborers, pipefitters

^a"Effect" (1974) and "Scheduled" (1980).
^bO'Connor (1969).
^c"The Effects" (1988).

Proctor & Gamble

The most publicized study of construction overtime is that made by Proctor & Gamble at their Green Bay, Wisconsin, operation. The study was first published as a Business Roundtable (BRT) report ("Effect" 1974) and was reissued in 1980 as part of the Construction Industry Cost Effectiveness Project ("Scheduled" 1980). Figs. 1 and 2 show the reported effect on productivity of extended overtime for a period of 12 weeks. As stated in both reports, the figures represent "the reduction in productivity normally experienced on projects operated on a basis of 50 hours per week and 60 hours per week....These observations are on a weekly basis with all completed work recorded from physical count or measurement and the work hours expended obtained from actual payroll hours. The curves reflect the averages of many observations" [("Scheduled" 1980) page 10].

The data in Figs. 1 and 2 are based on a comparison of actual work hours expended to a fixed standard base called a "bogey." The "bogey" standard is for a straight-time schedule. Unfortunately, the data are not a comparison between actual productivity on straight time and overtime productivity. The 1974 and 1980 reports contain the following warning with respect to comparisons of various data sets: "Direct comparisons of various data are difficult since all measurement of productive effort is not referenced to a Fixed Standard. The Industrial firm's data on productivity is based on Fixed Standards and a performance of 1.0 may not be the same as a performance of 1.0 referenced to some other standard of comparison. As a result, a 30% reduction of productivity in one set of data could compare with a 15% reduction reflected in another set of data due to this difference" [("Scheduled" 1980) page 15].

What is little known about the Business Roundtable reports is that the data all originated from a single project (i.e., Proctor & Gamble's Green Bay operation). Also, the nature of the Green Bay construction activities is not known. The curves are a composite view of a series of comparably short jobs on scheduled overtime covering a 10-year period. The project operations were carried out in a tranquil labor climate and the field management was reported to be excellent.

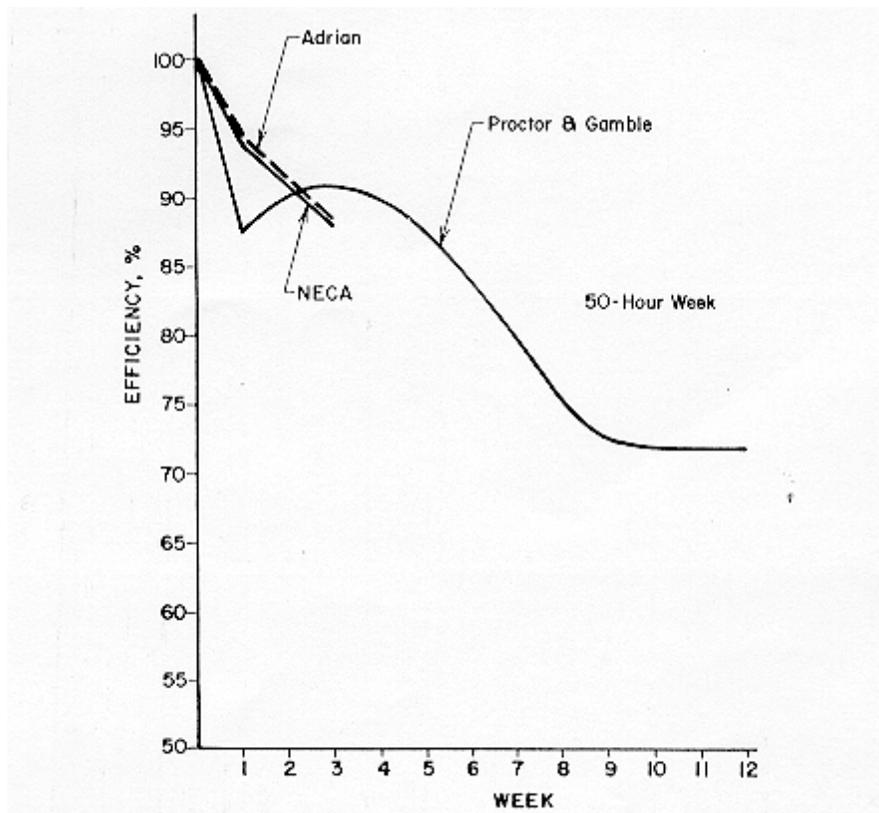


FIG. 1. Summary of Cumulative Effect of Overtime on Productivity, 50 hr Work-week

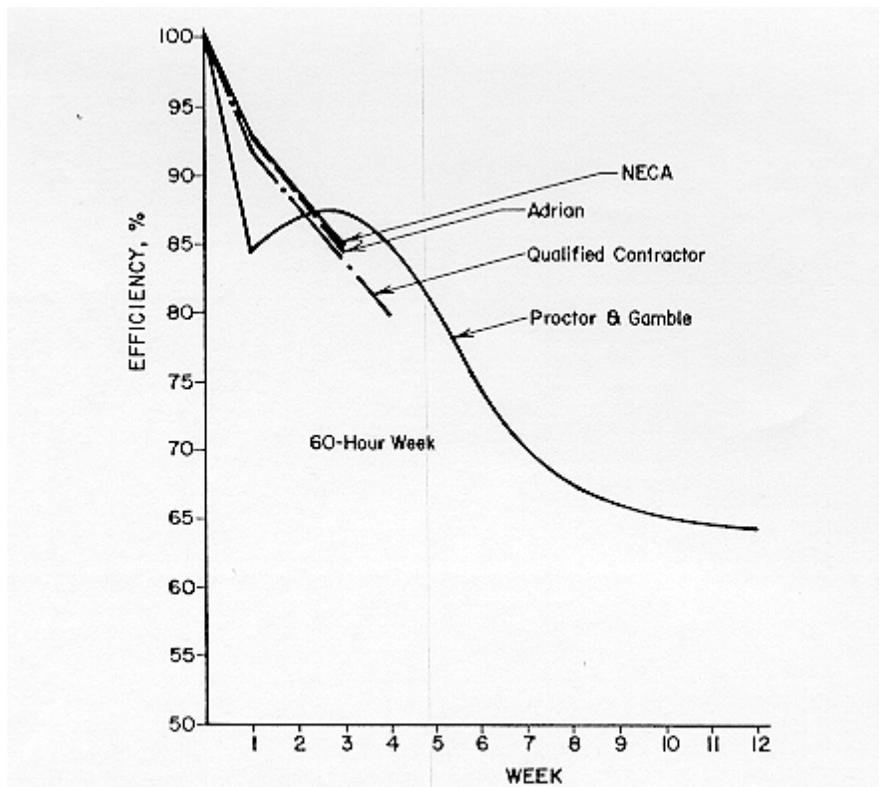
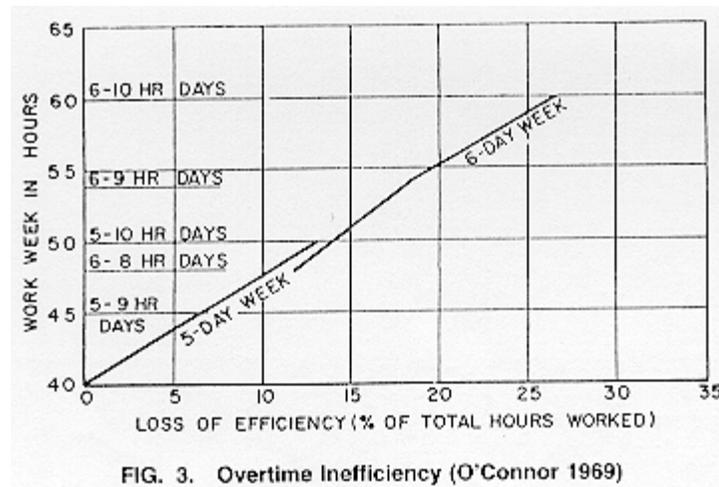


FIG. 2. Summary of Cumulative Effect of Overtime on Productivity, 60 hr Work-week

Foster Wheeler

A technical paper by L. V. O'Connor described the experiences of Foster Wheeler in constructing five large fossil boilers in the Ohio Valley between 1963 and 1968 (O'Connor 1969). The curve in Fig. 3 shows the results. The paper reported an average productivity decline of 7.9% per year during the period because of a variety of factors, including overtime, over-manning, and labor strikes. Although it is not explicitly stated, the reader is left with the impression that the conclusions are based on the boilermaker craft. No other information is given, and it is not known how the overall trend of productivity losses from the other causes was factored into Fig.3. The percentage loss of efficiency is consistent with the BRT report if the scheduled overtime period is about five to six weeks.



Construction Industry Institute

In 1984, the Construction Industry Institute (CII) sponsored a three-year study of construction overtime ("The Effects" 1988). This study represents the only source of original data since the 1960s. The study also differs from the previous two studies in several important respects. The data base includes multiple projects, and the data were collected by direct observation rather than from project records. The focus is on the work of a single crew as opposed to an entire craft, and the study reported results for a number of crafts. The analyses are independent of the project estimate.

The study included seven projects. As shown in Table 2, the two natural gas recovery projects were in the early stages of completion and the refinery expansion project was nearing completion. One was a shutdown project, and another (project 4) was experiencing considerable productivity problems aside from the overtime situation. Project 5 was on a rolling 4/10 (four days of 10 hr each) schedule. Only on projects 3 and 4 were data collected on straight-time and overtime schedules.

TABLE 2. Project Characteristics in CII Overtime Study ("The Effects" 1988)

Project Number (1)	Project type (2)	Weekly work schedule (days/hours per day) (3)	Percent complete (4)	Number crafts (5)	Number of crews (6)
1	Refurbishment of distillation unit at a refinery	6/10 7/10	Unknown	Insulator	Unknown
2	Refinery expansion, including some punch list work	5/10 + 1/8 7/10	85-90	Insulator, pipefitter	4 9
3	Oil refinery shutdown	6/8 6/10 5/8	Unknown	Electrician	2
4	Fossil power plant	4/9 + 1/8 5/10 + 1/8	Unknown	Electrician, pipefitter	Unknown
5	Chemical processing plant	4/10*	Unknown	Electrician, pipefitter	Unknown
6	Natural gas recovery plant	5/10	15	Carpenter, ironworker, laborer, pipefitter	Unknown
7	Natural gas recovery plant	5/10	18	Laborer	Unknown

*Rolling 4/10 schedule.

The limitations of the study include the inability to compare overtime productivity to straight-time productivity, incomplete data-collection procedures, the use of moving-average calculations, and the inability to correlate changes in productivity to other factors and job-site conditions. The problems caused by these limitations are illustrated in Figs. 4 and 5, which show the overtime and straight-time productivities of electricians on project 4. No discernible patterns can be identified. On project 3, the electrician productivity was better on a six-day, 10 hr schedule than on straight time.

The CII study could not develop defensible conclusions relative to the effects of an overtime schedule, because the productivity trends for the same crews were not consistent. The report did conclude that productivity does not necessarily decrease on an overtime schedule. At best, fatigue did not seem to be a factor.

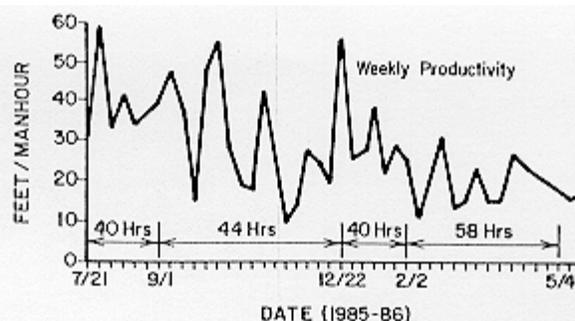


FIG. 4. Overtime Productivity, Cable Pulling Crews, 4/9s and 1/8 and 5/10s and 1/8 ("The Effects" 1988)

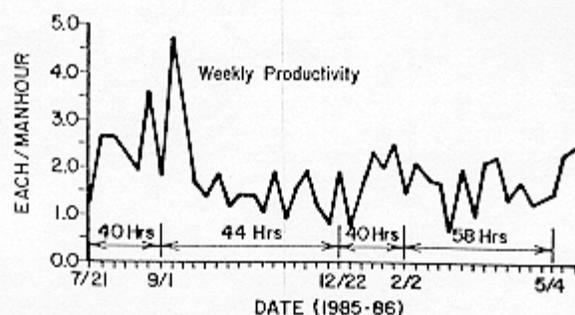


FIG. 5. Overtime Productivity, Termination Crews, 4/9s and 1/8 and 5/10s and 1/8 ("The Effects" 1988)

Other Studies of Effects on Construction Productivity

Five other sources of information summarizing the effects of construction overtime were identified in the literature. In each of these, the source of the data is either unknown, is considered to be more opinion than factual, or is a republication of other data. Table 3 summarizes these sources. As can be seen, most of this information is also significantly dated.

TABLE 3. Summary Data on Overtime Studies Based on Less-Than-Reliable Data

Source (1)	Time frame (2)	Number of projects (3)	Location of projects (4)	Project type (5)	Craft (6)
(Overtime 1969) NECA	1964	Unknown	Southeastern Michigan	Unknown	Electrical
(Overtime 1962) ^a NECA	1962	—	—	—	Unknown
C. F. Braun Inc. (unpub- lished 1979)	1970s	Unknown	Unknown	Unknown	Unknown
Adrian (1987)	1982	1	Chicago, Ill.	Unknown	Concrete
Qualified Contractor (Howerton 1969)	1964	Unknown	Unknown	Unknown	Unknown
MCA ("How" 1968; "Tables" 1968) ^b	1968	—	—	—	Unknown
ASA (Owner's 1979) ^c	1979	—	—	—	Unknown
AACE ("Effects" 1973) ^c	1973	—	—	—	Unknown

^aSurvey of 289 electrical contractors.

^bBased on Kassori's (1947a,b).

^cSame as Business Roundtable's "Effect" (1974) and "Scheduled" (1980).

National Electrical Contractors Association

In 1969, the National Electrical Contractors Association (NECA) published the results of a 1964 study of overtime done by the NECA Southeastern Michigan Chapter (*Overtime* 1969, 1989). The findings for electricians for 50 hr and 60 hr worksheets showing productivity losses as a function of the schedule used and the duration are presented in Figs. 1 and 2. The origin of the data is unknown.

NECA also published the results of a survey of 289 NECA members regarding their experiences with reduced productivity associated with overtime (*Overtime* 1962). These data are generally consistent with the Foster Wheeler data except for the 6/10 schedule. They are somewhat consistent with the 1969 NECA Michigan Chapter study except for several of the more demanding schedules.

C.F. Braun Inc.

Unpublished material from the C. F. Braun Inc. construction guide (unpublished 1979) contains data that are remarkably similar to the Foster Wheeler data and therefore raise doubts about their originality. No information is available about the origin of the data.

J. J. Adrian

Adrian [(1987) page 971 reported productivity losses on concrete activities as part of an analysis of a contractor claim. The project was in Chicago, Ill., and the work was performed in 1982 under ideal weather conditions (60-80° F). The losses of productivity are shown in Fig. 6.

Qualified Contractor

Qualified Contractor (Howerton 1969) published statistics on an overtime study conducted in 1964 [(Oglesby et al. 1989) page 260]. The data are plotted in Fig. 7. As the figure illustrates, the data are similar to those of Adrian (1987).

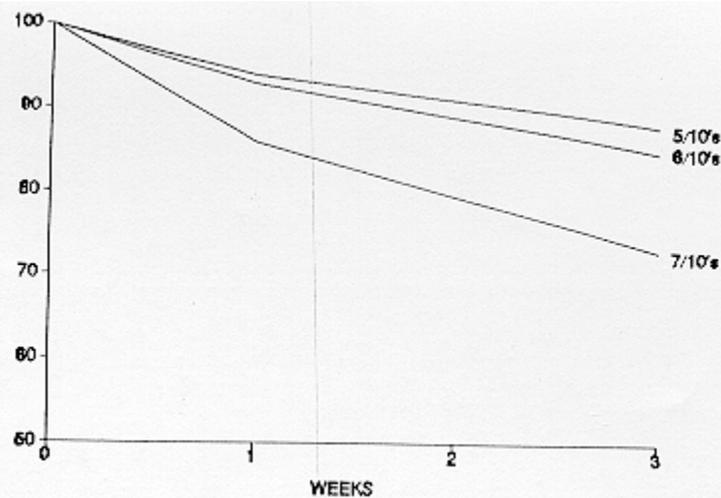


FIG. 6. Productivity as Function of Successive Weeks of Overtime (Adrian 1987)

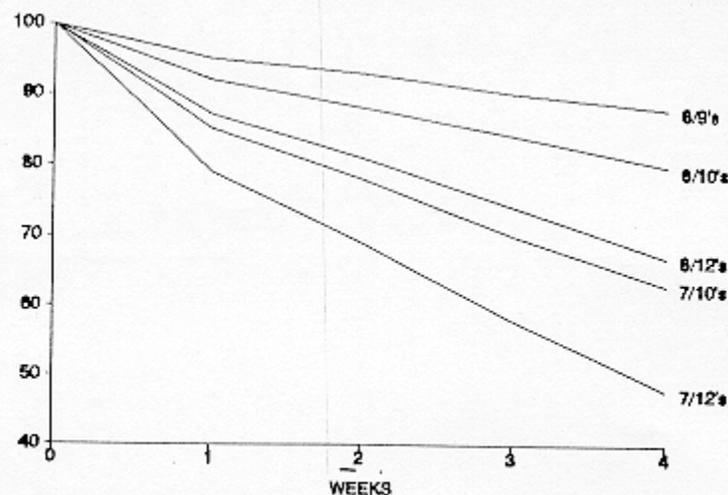


FIG. 7. Productivity as Function of Successive Weeks of Overtime (Howerton 1969)

Mechanical Contractors Association of America

The Mechanical Contractors Association (MCA) provides information to its membership in the form of management methods bulletins. *Bulletin No. 18A* (dated January 1968) ("How" 1968) and *Bulletin No. 20* (dated November 1968) ("Tables" 1968) were issued to assist contractors in the preparation of claims and change orders relative to overtime inefficiencies. Fig. 8 illustrates the losses that can be expected. As noted, the data are based on U.S. Department of Labor *Bulletin 917* (Kossoris 1947,i,b). As is indicated later, *Bulletin 917* summarizes data from the manufacturing sector, not from construction. Therefore, the MCA bulletins ("How" 1968; "Tables" 1968) do not contain original data.

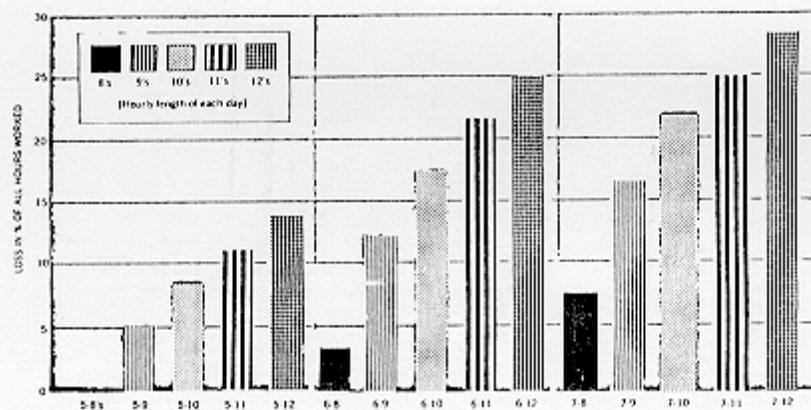


FIG. 8. Schedule of Efficiency Loss for Various Lengths of Workweeks (Kossoris 1947a,b; "How" 1968)

American Subcontractors Association

The Associated General Contractors, the American Subcontractors Association, and the Associated Specialty Contractors, Inc., jointly published a primer on overtime (*Owner's* 1979). The data are identical to those published by the Business Roundtable ("Effect" 1974; "Scheduled" 1980). Thus, the ASA primer contains no original data.

American Association of Cost Engineers

The American Association of Cost Engineers published a bulletin on overtime ("Effects" 1973). The data are identical to those published by the Business Roundtable ("Effects" 1974; "Scheduled" 1980). Therefore, the AACE bulletin contains no original data.

STUDIES IN MANUFACTURING SECTOR

A cursory review of the literature of overtime effects in manufacturing and other industries yielded very little quantitative information. The most notable reference is Bureau of Labor Statistics (BLS) *Bulletin 917*, published in 1947 (Kossoris 1947a,b). This report has been widely cited as a reliable source relative to construction ("Effect" 1974; "Scheduled" 1980; *Owiler's* 1979; "How" 1968; "Tables" 1968).

The 1947 BLS study involved 2,445 men and 1,060 women and covered 78 case studies at 34 facilities in a wide variety of manufacturing industries and settings such as foundries, machine shops, product packaging, and assembly and production lines. Production products included engines, airplanes, piston rings, metal bearings, airfield landing mats, hats and clothing, rubber hoses, office supplies, and cigars. Packaging activities included biochemicals, pharmaceuticals, and cough drops. Most of the work was indoors, some was machine paced, and most was highly repetitive. There were no construction activities included in the study.

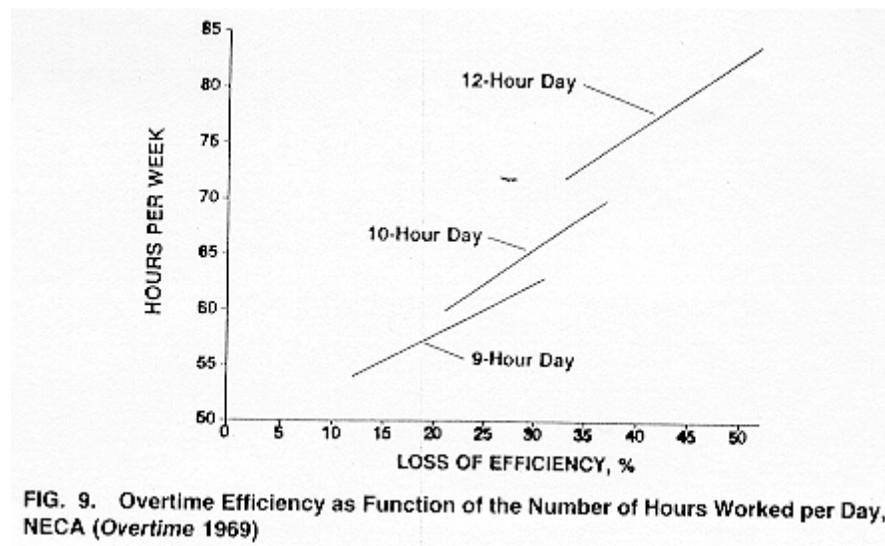
The results of the study showed that efficiency was impaired as the work schedule exceeded 40 hr/week. The average efficiency for 50 hr, 60 hr, and 70 hr weeks was 0.92, 0.84, and 0.78, respectively. The degree of inefficiency was affected by the work schedule, the physical exertion required, and the pace of the machine. Comparisons to prewar situations in which the same work schedule was used were possible in 15 cases. The study found that efficiencies were better in all cases during the wartime period. The gain in efficiency ranged from 0.7% to

29.0%. The average gain was 13.6%. Thus, it appears that patriotism was a significant variable, and that the study results may not be applicable to other situations.

ANALYSIS OF HOURS PER DAY

Aside from determining the hours per week to be worked, one must also decide on the number of work hours per day. Common sense dictates that the rate of loss efficiency should accelerate nonlinearly as the length of the workday increases and as the number of hours per week increases.

Figs. 9-12 show the reported loss of efficiency as a function of the length of the workday and the number of hours per week. These figures provide somewhat conflicting and irregular results. Fig. 9 shows patterns that would be expected, although some might expect the differential between the 10 hr and 12 hr days to be greater. In Fig. 9, the differences appear to be almost linear. However, Figs. 10-12 show that the loss of efficiency is not related to the hours worked per day. In fact, Adrian's (1987) data show that in some ranges the longer workday is more efficient. Thus, the curves in Figs. 11 and 12 do not seem consistent with expectations.



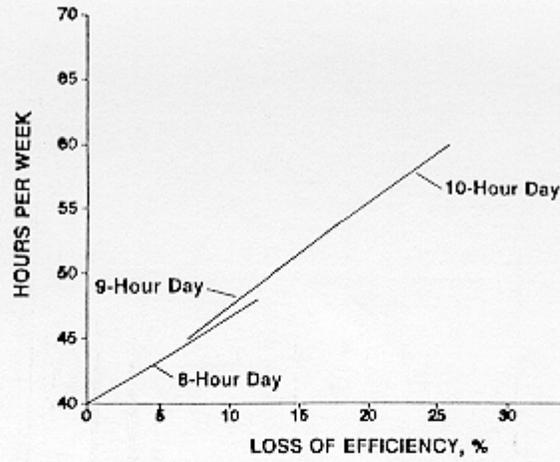


FIG. 10. Overtime Efficiency as Function of the Number of Hours Worked per Day, Foster Wheeler (O'Connor 1969)

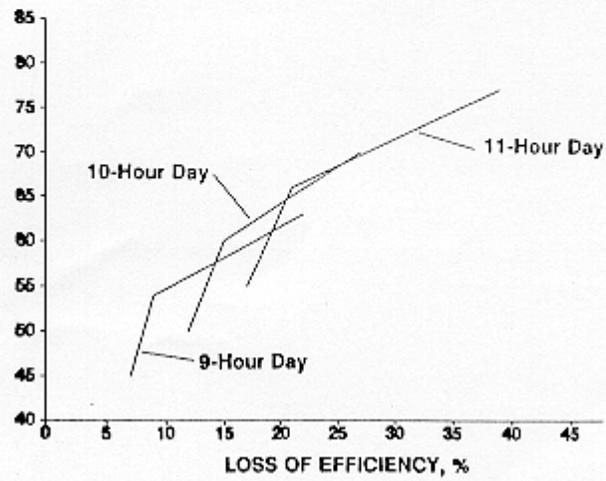


FIG. 11. Overtime Efficiency as Function of the Number of Hours Worked per Day, Adrian, Based on 21 Days (Adrian 1987)

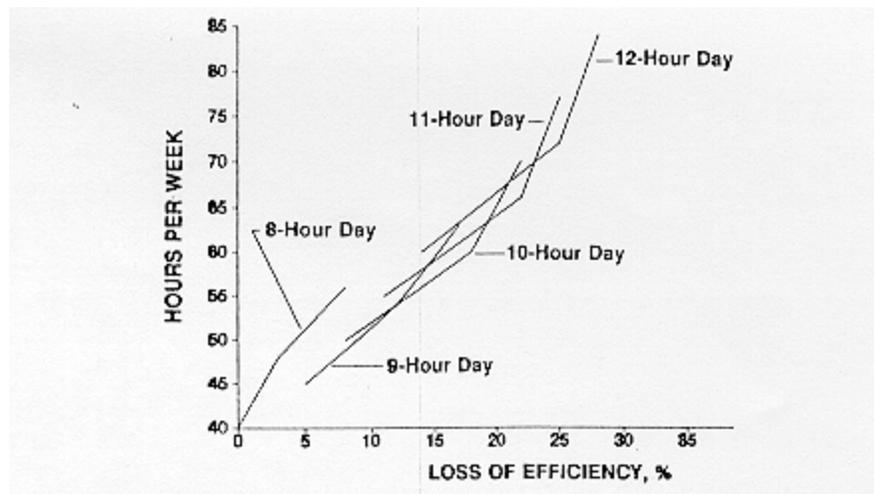


FIG. 12. Overtime Efficiency as Function of the Number of Hours Worked Per Day, U.S. Bureau of Labor Statistics (Kossoris 1947a,b)

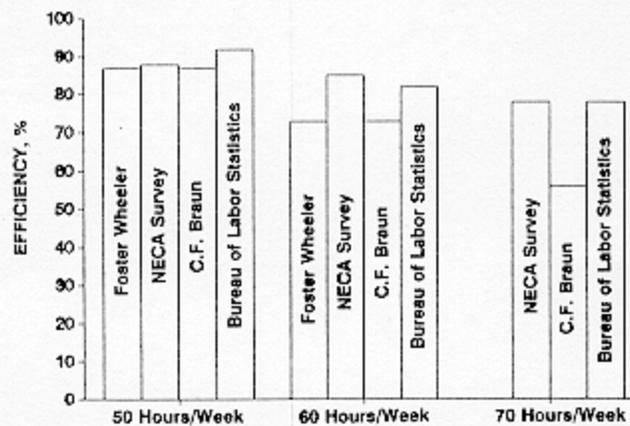


FIG. 13. Summary of Reported Efficiency for 50, 60, and 70 hr Workweeks

SYNOPSIS

The literature review reveals very little original data relative to construction overtime activities. Except for the CII ("The Effects" 1988) and Adrian (1987) studies, all of the data originate from the 1960s or earlier. Very little is known about how the data were collected or the conditions under which the work was performed. Fig. 13 shows the reported efficiency for various 50 hr, 60 hr, and 70 hr workweeks. The basis for comparison is a 10 hr workday.

The results are generally consistent in that there is about a 10% increase in efficiency losses for each additional 10 hr per week added to the schedule beyond 40 hr. However, the conclusions that can be drawn from these data are somewhat uncertain, especially for the longer schedules.

Figs. 1 and 2 show the change in efficiency as a function of time for 50 hr/week and 60 hr/week schedules. The findings are generally consistent, although there is very little data on which to base conclusions.

The literature is inconsistent relative to the loss of efficiency as a function of the length of the workday. In one instance, the decrease in efficiency loss appears linearly related to the length

of the workday; whereas in three other instances, loss of efficiency appears to be unrelated.

STUDIES OF DAYS PER WEEK

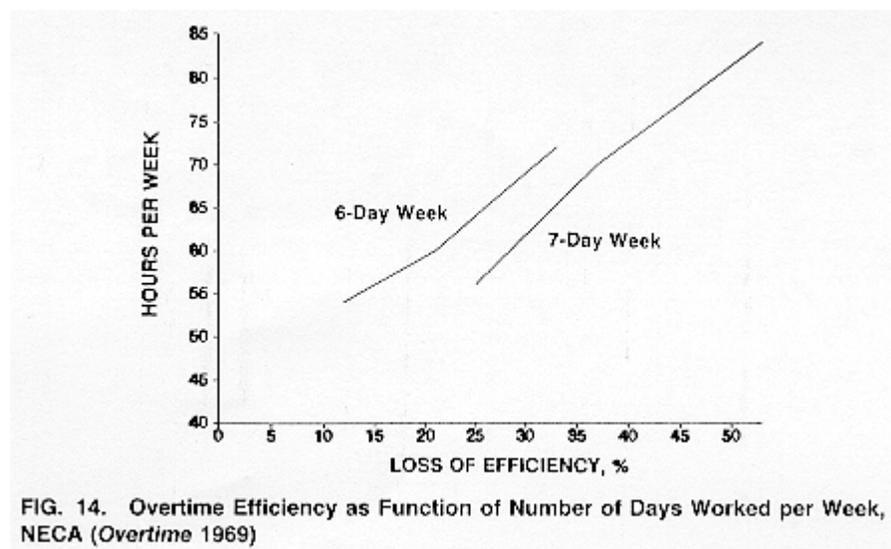
An increase in the number of hours worked can be made by increasing the hours worked per day, the number of days worked per week, or both.

Considerable uncertainty exists as to which is the most effective work schedule, although there is research to support the notion that workers need at least one day per week to relax (Kossoris 1947a,b).

Five-, Six-, and Seven-Day Workweeks

Common sense suggests that the longer the workweek and the more days per week, the greater the inefficiencies. The daily inefficiencies of starting up and winding down have been noted in other literature. Therefore, in choosing between two overtime schedules, both with the same number of hours per week, the better choice should logically be the one with the fewest days per week.

A number of the studies addressed the inefficiencies of working five days or more per week. These can be grouped into three general categories. The first category are those showing the expected trend of greater inefficiencies as the schedule extends to six and seven workdays. Fig. 14 shows the data from the NECA study (*Overtime* 1969). Using a 60 hr week as the basis for comparison, it shows that the seven-day schedule is about 7% less efficient than the six-day schedule.

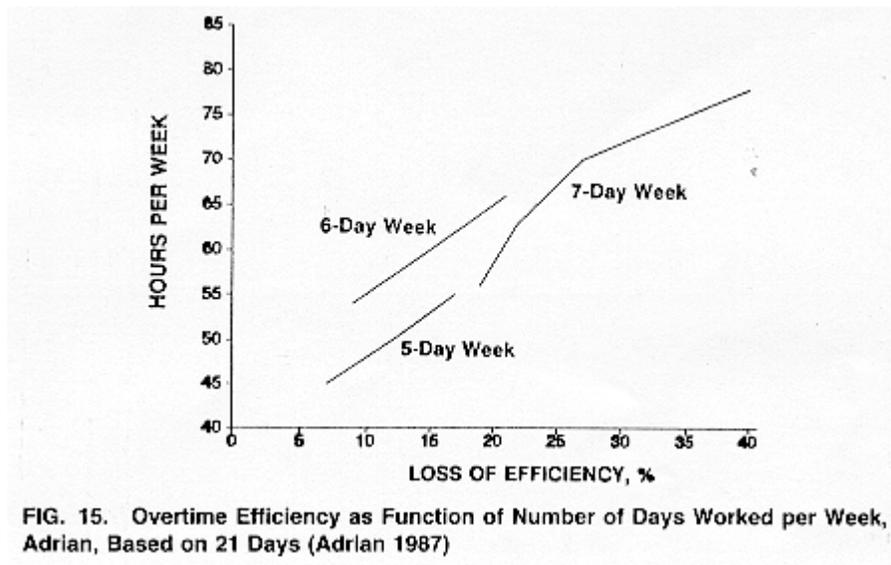


The second category included data from the Foster Wheeler (O'Connor 1969), C. F. Braun Inc. (unpublished 1979), Adrian (1987), and Bureau of Labor Statistics (Kossoris 1947a,b) studies. Fig. 3, from the Foster Wheeler study, is typical; it shows that the number of days per week has little influence on the efficiency of construction operations. Figs. 15 and 16 actually show that the five-day schedule is less efficient than the six-day schedule when the number of hours worked per week is less than 55.

In the third category, Fig. 17, from the 1969 NECA survey, shows the longer workday

schedules to be more efficient. The five-day schedule is less efficient than the six-day schedule. The curve for the seven-day schedule shows a 70 hr/week schedule to be more efficient than a 56 hr schedule.

In reviewing these data, one can readily discard the NECA survey data [(*Overtime* 1969) (Fig. 17)] as erroneous. While the results from the second category cannot be discarded, they can also be viewed with some degree of suspicion. Only Fig. 14 shows results that are consistent with generally accepted expectations and knowledge in the construction industry.



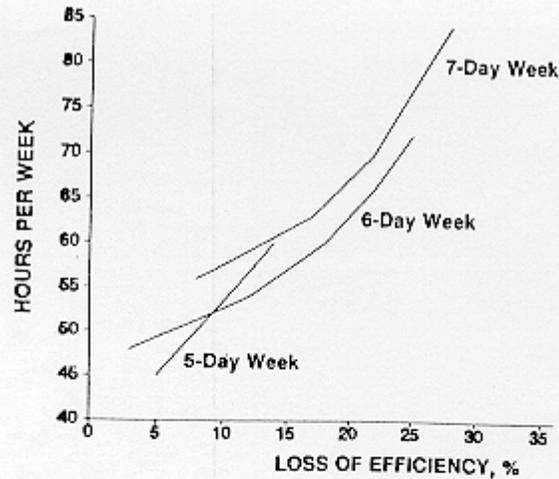


FIG. 16. Overtime Efficiency as Function of Number of Days Worked per Week, U.S. Bureau of Labor Statistics (Kossoris 1947a,b)

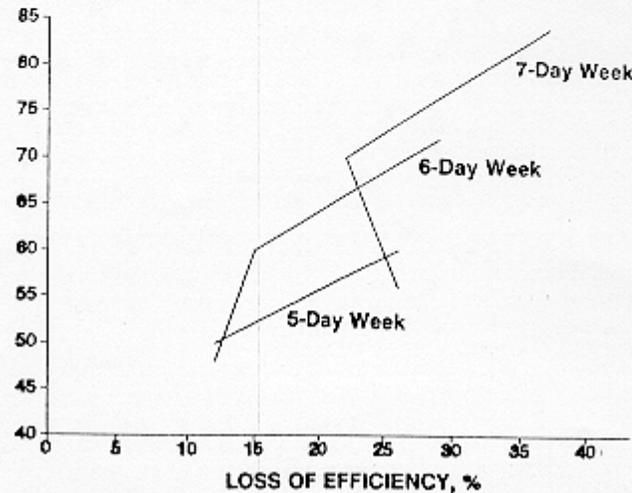


FIG. 17. Overtime Efficiency as Function of Number of Days Worked per Week, NECA Survey (Overtime 1962)

The Four-Day, 10 hr Schedule

The four-day, 10 hr/day schedule has gained popularity in the construction industry. An extension to this schedule is the rolling 4/10 schedule, in which two work forces alternate; that is, each work force is scheduled for four days on and three or four days off. In this way, the project can be manned continuously.

Based on the experiences of Daniel International (McConnell 1982), the 4/10 schedule has the following advantages.

- More productive work hours (less work starts and stops).
- Reduced travel cost.
- Increased employee morale.
- Attraction of workers from a larger labor market.
- Lower absenteeism and turnover.
- The option to make up rain-out days on Friday, thus avoiding the expense of weekend

work schedules.

The disadvantages of the 4/10 schedule are the following.

- Engineering firms and the owner's administrative personnel operate on a different schedule.
- Owner personnel may have to adjust the normal work schedule.

Two studies have cited certain advantages and disadvantages of the 4/10 schedule in quantitative and qualitative terms. These are as follows.

First, an in-house study by Daniel International (*The Four- Ten* 1979 based on 10 years of experience with the 4/10 schedule, concluded that the 4/10 schedule was superior to other schedules. This conclusion resulted from both quantitative and qualitative analyses.

The quantitative analysis was a 20-week work-sampling study at a test site in the southeastern United States during the period from November 1975 to mid-March 1977. During this time, two schedules were used: a 4/10 and a 5/8. The work-sampling results are summarized in Table 4.

TABLE 4. Work Sampling Results

Work schedule (1)	Direct activity (%) (2)	Support activity (%) (3)	Delays (%) (4)
5/8s	63.0	19.1	17.9
4/10s	63.3	19.7	17.0

The study also examined the level of activity during the beginning and end of the shift. The percentage of direct activity during the first and eighth hours on the 5/8 schedule was no different than the ninth and tenth hours on the 4/10 schedule. While direct work activity is not well correlated to labor productivity (Thomas 1991), it would appear that differences in the level of activity on the site as a function of the schedule are insignificant.

Second, as part of the overtime study by CII ("The Effects" 1988), one project in the study used a rolling 4/10 schedule. The project was the construction of a chemical processing unit. Data were collected on crews installing pipe, conduit, tubing, terminations, cables, wire, and feeders.

The study made no comparison between the 4/10 schedule and any other. The results showed that during the seven-month duration of the study, the general productivity trend for all of the crews did not change, although there were brief periods of improvement and deterioration. The report made no assessment of the efficiency of the 4/10 schedule compared to other schedule alternatives.

Synopsis

Overall, the studies of different work schedules are inconclusive as to which alternative schedule is most efficient. Several studies show that a shorter workweek is best; and one study shows that longer workweeks are preferable. However, most studies show very little difference.

With respect to the 4/10 schedule, only one source was identified. Daniel International (*The Four- Ten* 1979) concluded that the 4/10 schedule was more efficient than a normal schedule of five 8 hr days.

CONCLUSIONS

The literature on scheduled overtime was found to be very sparse; dated to the late 1960s and earlier; based on small sample sizes; and largely developed from questionable or unknown sources. Although there appears to be a number of data sources, this is an illusion because many of the articles and publications quote other sources while providing no new data or insight. Where the data source is known, other pertinent information, such as the environmental and site conditions, quality of management and supervision, and labor situation, is unknown. The various graphs and data that have been published are inherently unreliable, except perhaps to suggest an upper bound on the losses of efficiency that might be expected. The literature offers no guidance as to what circumstances may lead to losses of efficiency.

With respect to the loss of efficiency as a function of the number of hours per day and the number of days per week, the literature provides strange and largely unbelievable results. The results from the southeastern Michigan NECA study (*Overtime* 1969) and as reported in *Qualified Contractor* (Howerton 1969) both show losses of efficiency as the length of the workday increases and as more days per week are worked. These data suggest that the six-day week is about 7% (absolute) more efficient than the seven-day week. The 10 hr workday compared to a 9 hr workday results in a loss of efficiency of about 4% (absolute). The 12 hr day results in a loss of efficiency of another 7-8% (absolute).

The studies by Foster Wheeler, C. F. Braun Inc., Adrian, the Bureau of Labor Statistics, and the Southeastern Michigan NECA survey show that efficiency is not related to the number of work hours per day or the number of workdays per week. Since it is not possible to increase the total hours per week in any other way, it is concluded that these studies are flawed.

ACKNOWLEDGMENT

This paper is based on research sponsored by the Construction Industry Institute (CII). The support of the Overtime Task Force is gratefully appreciated.

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PAPER 6

**“Quantifying the Impact of
Schedule Compression on Construction Labor Productivity”
by Chul-Ki Chang, Awad S. Hanna,
Jeffrey A. Lackney, and Kenneth T. Sullivan
2005, ASCE.**

QUANTIFYING THE IMPACT OF SCHEDULE COMPRESSION ON CONSTRUCTION LABOR PRODUCTIVITY

Chul-Ki Chang¹, Awad S. Hanna², Jeffery A. Lackney³, Kenneth T. Sullivan⁴

ABSTRACT

In a typical construction project, a contractor may often find that the time normally expected to perform the work has been severely reduced. The reduction of time available to complete a project is commonly known throughout the construction industry as schedule compression. Schedule compression is a problem because it negatively impacts labor productivity in various ways, and it becomes a source of dispute between the owners and contractors. This paper investigates how schedule compression affects construction labor productivity and provides a model that quantifies the impact of schedule compression on labor productivity by analyzing 66 mechanical projects and 37 sheet metal projects collected from across the United States. The model can be used in a pro-active manner to reduce productivity losses by managing the factors affecting productivity under the situation of schedule compression. Another useful application of the model is its use as a litigation avoidance tool after the completion of a project.

KEYWORD

Schedule compression, Schedule acceleration, Labor productivity, Dispute resolution

INTRODUCTION

Time conservation is a prime concern for both the owners and contractors on construction projects due to the fact that time inevitably equals money; consequently time savings greatly improve profits, while a loss of time can lead to financial distress. If substantial losses of time are encountered during a project, late completion will become a significant issue. If a project is extended beyond the original completion date, the owner may lose business opportunities or income derived from the use of a facility. Simultaneously, to the extent that the contractor is responsible for the delay, the contractor may be charged a penalty for late completion based on the liquidated damages clause in the contract. Therefore, timely completion is one of the basic objectives of a construction project, along with cost, quality,

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and safety. However, timely completion can often be accompanied by its own problems. Frequently, the owner requires the contractor to complete the work more quickly than originally needed, or requires additional work to be performed within the original time scale. Sometimes, unforeseeable circumstances outside the control of the contractor may cause a reduction of time available for completing the work. (Noyce and Hanna 1997, Horner and Talhouni 1995). Besides these reasons, there are numerous other scenarios leading to schedule compression. When these circumstances arise, the contractor is forced to speed up 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. Schedule compression is defined in this study as a reduction of time available to complete the work from the normal experienced time or optimal time for the type and size project being planned within a given set of circumstances (Construction Industry Institute 1994).

At first examination it may seem that schedule compression would be an effective solution for problems associated with time. Unfortunately, schedule compression can negatively impact 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 schedule compression affects construction labor productivity is crucial for increasing project performance, avoiding disputes, and maintaining sound financial status of a company.

Direct costs incurred during schedule compression can be easily tracked, so it is usually not disputable. The more significant cause of increased project costs due to schedule compression is lost labor productivity. A review of relevant court cases show that contractors usually fail to provide evidence showing the work was accelerated, and a cause-effect relationship between the schedule compression and increased cost. Contractors need to prove the work was accelerated, and that additional costs and lost productivity were incurred as a result. Without demonstrating damages and being able to quantify them, the additional cost of lost productivity can not be compensated.

Although many studies have been conducted on the issue of schedule compression, most of the studies deal with schedule compression with the objective of minimizing cost escalation while achieving schedule compression. Many mathematical and optimization models have been developed as a means of calculating the required compression of individual activities on the project schedule. However, these methods are quite complex in nature and provide little practical use on the project site due to their complexity (Noyce and Hanna 1998). Relatively little effort has been made to determine the relationship between schedule compression and labor productivity.

The purpose of this study is to investigate how and why schedule compression affects construction labor productivity and to quantify the impact of schedule compression under the given project conditions on labor productivity at the project level.

IMPACT OF SCHEDULE COMPRESSION ON LABOR PRODUCTIVITY

Figure 1 compares manpower loading graphs under situation of schedule compression with

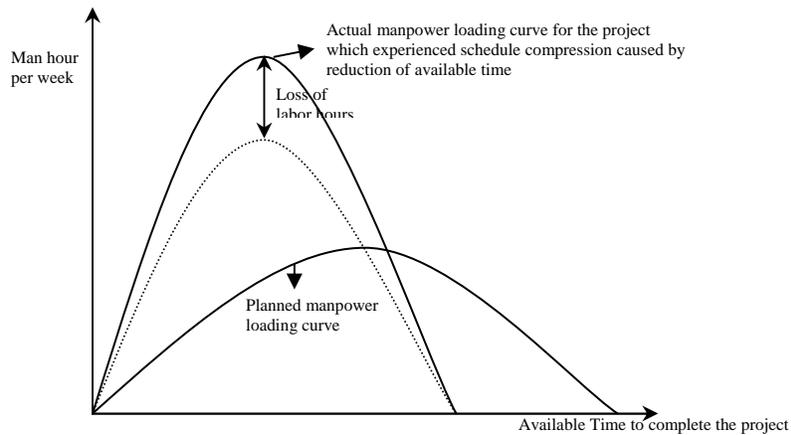


Figure 1: Lost Labor hours due to Schedule Compression

normal conditions. The area under each curve represents total manhours to complete the project. The area under the dotted curve should be theoretically same as the area under the planned manpower loading curve. As can be seen in Figure 1, manhours under schedule compression are much greater than during normal operation. The additional manhours are due to inefficiency caused by accelerating the work as well as manhours required to accelerate the work. This is because schedule compression affects labor productivity in various ways. For example, the planned sequence of activities, and flow of resources, including labor, materials, equipments and subcontractors, may be impacted (Peles 1977, Borcharding 1980, Marchman 1988, Long 1988, Haneiko and Henry 1991, Thomas 2000). If more workers are added and more activities must be accomplished concurrently in a limited working space, the jobsite may not accommodate the number of workers or activities. This may cause congestion and a high density of workers resulting in a productivity loss (US Army Corp. of Engineers 1979, Peles 1977, Marchman 1988, Long 1988). As the number of on-site workers increases in size, it is critical that a corresponding increase be made to the supervisory staff, materials, tools, and equipment. Dilution of supervision plus a shortage of materials, tools, and equipment can lead to a productivity loss (Peles 1977, Thomas 2000). Besides the above reasons, there are many other ways that schedule compression can affect labor productivity. Figure 2 illustrates how the labor productivity losses occur when schedule compression is present. The inputs are situations that require schedule compression. 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 schedule compression and outputs are some possible results of schedule compression.

DATA COLLECTION

To quantify the impact of schedule compression on labor productivity, 66 mechanical projects and 37 sheet metal projects from contractors with headquarters in 20 states, with the projects themselves being worked in 28 different states were analyzed. The value of

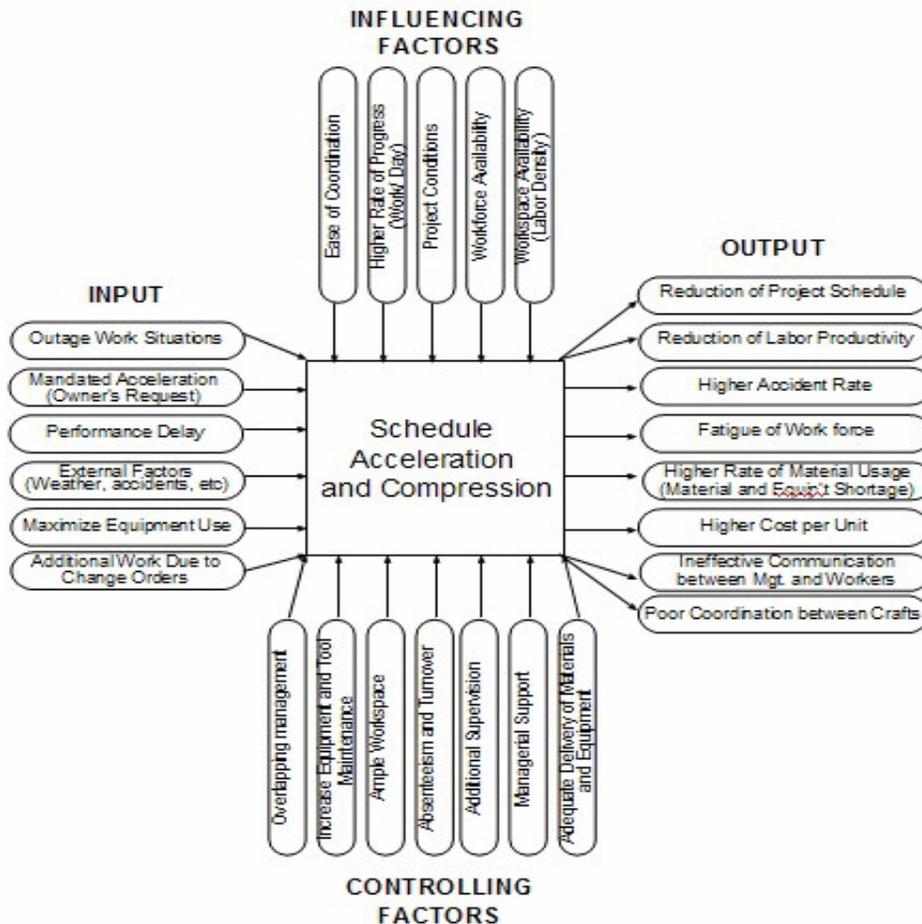


Figure 2: Schematic Structure of Schedule Compression

construction put-in-place per year by these companies ranged from \$3.9 million to \$ 170 million and these contractors worked a range of total manhours of direct labor (averaged over the last three years) from 9,690 manhours to 1,977,300 manhours. The work entailed new construction (43%), addition or expansion construction (19%), renovation (19%), and combinations of these (13%). Types of construction of projects are commercial (12%), institutional (35%), industrial (38%), manufacturing (6%), residential (2%), and others (8%). The types of work performed on these projects are HVAC (43 %), plumbing (22 %), process piping (24%), fire protection (4 %), and other (7%).

QUANTITATIVE DEFINITION OF SCHEDULE COMPRESSION

Although many studies have been conducted on schedule compression, the quantitative definition of schedule compression has not been clearly established. Before quantifying the impact of schedule compression on productivity, the quantitative definition of schedule

compression needs to be established to determine whether a project has experienced schedule compression.

Based on the fact that schedule compression occurs when a contractor is required to do a certain amount of work in a shorter period of time than the normal or optimal time typical for the type and size of project in a given set of circumstance, the quantitative definition of schedule compression may be determined as the difference between normal project duration for a certain type and size of project and actual duration spent to complete the project.

NORMAL DURATION

The “Normal duration” for a certain type and size of project in this study is defined as the time required for completing a project with a normal crew size and normal weekly work hours. Normal weekly workhours in the construction industry is generally 40 hours, working eight hours per day and five days per week. In this study, the average number of workers, based on project size, was considered as the normal crew size. Therefore, “Normal duration” can be defined as follows.

$$NormalDuration = \frac{ProjectSize}{NormalCrewSize \times 40} \dots\dots (1)$$

where, project size is in manhours by using actual total manhours consumed for the project.

Using the data collected for this study, equations showing the relationship between average crew size and project size for mechanical projects and for sheet metal projects were developed as follows:

- Mechanical Work:

$$Log (Normal Crew Size) = -1.03 + 0.455 * log (Project Size) + 0.380 Industrial \dots\dots (2)$$

- Sheet Metal Work:

$$Normal Crew Size = 1.587 + 2.7E^{-4} * (Project Size) \dots\dots (3)$$

From the normal crew size obtained from Equation (2) and (3), the normal duration for a certain type and size of project can be calculated by using Equation (1).

PERCENT SCHEDULE COMPRESSION

To generalize, the concept of % Schedule Compression was developed. Percent Schedule Compression (% SC) can be used to determine if a project experienced schedule compression or not before or during implementation of the project and can work as an indicator of how much time was compressed. Percent Schedule Compression (% SC) can avoid any bias from project size, project duration, work hours per week from different crew scheduling methods, the number of workers involved in the project, whether a time extension was granted or not, and if the project was initially compressed or poorly planned.

$$\% Schedule Compression = \frac{NormalDuration - ActualDuration}{NormalDuration} \dots\dots (4)$$

Percent Schedule Compression (% SC) can have both positive and negative values. A positive value means the project was completed in less time than the normal duration. In other words, the project experienced schedule compression for other reasons, such as a delay in the middle of project, a late start, additional work, or many change orders. A Percent Schedule Compression (% SC) of zero represents that the project was completed as planned, or enough time extension was granted to accommodate the increased work scope or changed work. A negative % schedule compression indicates more time was granted than needed, or the work scope was reduced while the project duration remained as planned.

DEVELOPMENT OF QUANTIFICATION MODEL

EFFICIENCY LOSS

Efficiency is a commonly accepted method used to quantitatively calculate labor productivity. Efficiency is defined as the ratio between the actual labor hours expended to complete the project and the budgeted base hours (Hanna, 2001). 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 (%LostEff) is defined as given in Equation 5:

$$\%LostEff = \frac{Total\ Actual\ Direct\ Labor\ Hours - Budgeted\ Direct\ Labor\ Hours}{Total\ Actual\ Direct\ Labor\ Hours} * 100 \quad \dots\dots (5)$$

PREDICTOR VARIABLES

Percent schedule compression is a good indicator for determining whether the project schedule was compressed, as well as, how much the project schedule was compressed. Obviously, there are other factors that interact with the amount of schedule compression, such as project size, type of project, and contractor's project management, or that are caused by schedule compression, including overtime, shift work, overmanning, crew size increase, work hour increase, and stacking of trades. The other factors amplify or mitigate the impact of schedule compression on labor productivity. Forty two variables were tested through hypothesis testing. These 42 factors were derived from the questionnaire developed to collect project data for this research. The factors were selected through multiple phases including literature review, a conference and phone interviews with contractors, and pilot study. They includes project characteristics (project size, type of project, type of work and etc.), contractors project management practice (Use of project management tools such as Critical Path Method, Manpower Loading Chart, progress tracking method and etc.) project manager's experience, schedule compression methods (overtime, overmanning, shift work).

MODEL FOR DETERMINING LOSS OF LABOR PRODUCTIVITY DUE TO SCHEDULE COMPRESSION

Multiple regression analysis was performed against % LossEff to predict productivity loss caused by schedule compression. Eight variables were selected in the final model through

stepwise method. The regression equation to predict the impact of schedule compression on labor productivity is as follows:

$$\begin{aligned}
 \%LossEff = & - 0.0723 + 0.417 \%Schedule\ compression \\
 & - 0.00252 Actual\ manpower\ at\ peak \\
 & + 0.0591 Ratio\ of\ actual\ and\ estimated\ manpower\ at\ peak \\
 & - 0.0474 Schedule\ Management + 0.193 Industrial \\
 & + 0.102 \%Beneficial\ occupancy \\
 & + 0.594 \%Change\ order\ for\ schedule\ compression \\
 & + 0.00239 Actual\ project\ duration \qquad \dots\dots (6)
 \end{aligned}$$

Table 1. Statistical Analysis of Final Model

Predictor	Coefficient	P-value
Constant	-0.07233	0.292
%Schedule compression	0.41705	0.000
Actual manpower at peak	-0.0025193	0.000
Ratio of actual and estimated manpower at peak	0.05911	0.000
Schedule management?	-0.04737	0.090
Industrial?	0.19307	0.000
% Beneficial occupancy	0.10211	0.062
% Change order for schedule compression	0.5938	0.000
Actual project duration	0.0023906	0.001

Table 2. Calculation and applicable range of factors included in the final model

Predictor	Calculation	Applicable range
Constant	1	
%Schedule compression	$\frac{\text{NormalDuration} - \text{ActualDuration}}{\text{NormalDuration}}$	0.01 to 0.89
Actual manpower at peak	The number of Sheet metal(Mechanical) workers at peak	10 to 90
Ratio of actual and estimated manpower at peak	$\frac{\text{Actual Manpower at Peak}}{\text{Estimated Manpower at Peak}}$	1 to 4.53
Schedule management?	Was a CPM schedule created and regularly updated for this project? 0=No, 1=Yes	0 or 1
Industrial?	Either industrial or all others: 0=Others 1=Industrial	0 or 1
% Beneficial occupancy	$\frac{\text{Total work hour executed on an operating unit}}{\text{TotalWorkHour}}$	0 to 1
% Change order for schedule compression	$\frac{\text{Total Change Order Hour for Schedule Compression}}{\text{TotalChangeOrderHour}}$	0 to 0.4
Actual project duration	Actual Project duration in weeks	2 to 84

The R^2 value for this above equation is 76.8%. Table 1 shows the result of the statistical analysis of the final model. The p-value of the regression analysis was 0.000, and p-values for predictors in Table 1 were also statistically significant, indicating a relatively strong regression model.

Table 2 gives the calculations, and applicable range of each of the independent factors included in the final quantification model. It should be noted that the final model is not valid for a project containing a factor that is not within the applicable range. Projects that contain variables that are not within the parameters of the model should not be used to predict productivity loss due to schedule compression from the final model.

VALIDATION OF FINAL MODEL

CROSS VALIDATION

The model was validated through cross-validation. For cross-validation, the data were divided randomly into five subsets. The model was refit using four subsets, and then the prediction accuracy was determined with the remaining subset. This process was repeated for all five subsets. The results shows 73% of the projects deviated within $\pm 10\%$.

VALIDATION FOR PROJECT TYPE, SIZE, AND DURATION

Validation of the final model was also performed to see if there is any bias due to type of work, different project size, and different length of project duration. The data used to develop the final model were regrouped into sheet metal projects and mechanical projects, and then the predicted value of % Delta was compared with actual % Delta. The average deviation of sheet metal projects is -1% and that of mechanical projects is 1%. This means the final model can be used on both types of work.

To see if the final model can work on different sizes of projects, the projects were grouped into three groups depending on project size. The first group includes projects with actual manhours less than 20,000 hours. The second group contains the projects whose actual manhours are greater than 20,000 manhours, but less than 100,000 manhours. The last group represents projects whose project size is greater than 100,000 manhours. The predicted productivity loss obtained from the final model was compared with actual productivity loss. The test result says the average deviations of small project, medium project, and large project are 1%, -1%, and 2%, respectively. This confirms there is no bias in project size when using the final model.

The same process was performed for different project durations. The projects were grouped into three groups again depending on project duration. The first group includes projects where their actual duration is shorter than a half year (26 weeks), the second group contains the projects whose actual duration is longer than a half year, but shorter than one year. The third group represents projects whose project duration is longer than one year. The test result shows the average deviations of short project, medium project, and long project are 1%, 0%, and 0%, respectively. This confirms there is no bias in project duration when using the final model.

SCOPE OF STUDY

Off-project costs may accrue when contractors are forced to reallocate resources from other projects to a project that is experiencing schedule compression. Furthermore, the commitment of schedule compression on a certain project will tie up important resources and hence limit the company's ability to undertake other work. Consequently, the loss of productivity or even profit from a secondary project is not considered in the analysis of the losses of an impacted project under the Delta approach (Hanna 2001). This study is limited to mechanical and sheet metal projects with lump sum contracts and a traditional project delivery system.

CONCLUSIONS

It is clear from the findings from this study that various scenarios leading schedule compression exist, and it is that these scenarios negatively affect labor productivity. This research can assist labor-intensive specialty trades not only in understanding the impact of schedule compression on labor productivity, but also practically calculating productivity loss and labor cost. The model developed through this research can be used in a pro-active manner to reduce productivity loss due to schedule compression by managing the factors affecting productivity under the situation of schedule compression. Another useful application of the model is as an anti-litigation tool after completion of a project. For dispute resolution, the values for % Delta obtained from the model could be used as the basis of negotiation between contractors and owners.

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