Impact of Extended Overtime on Construction Labor Productivity

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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.

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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.

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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 craftspersons 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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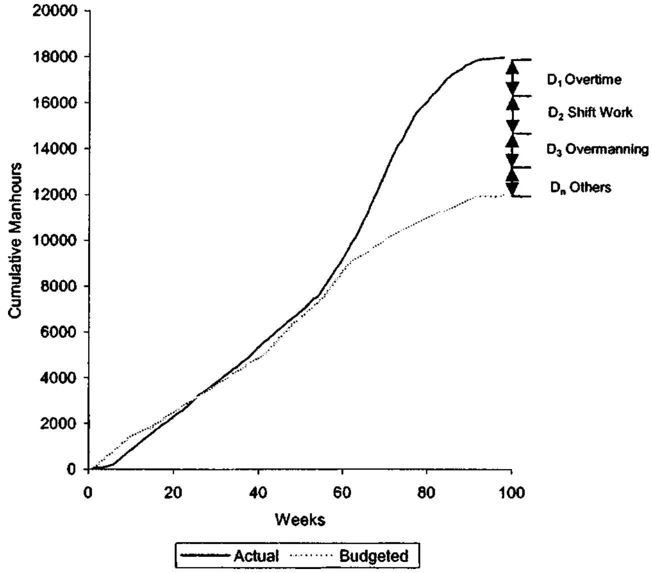

Fig. 1. Factors approach

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

	Crew scheduling technique Days(h)			
Schedule productivity characteristics	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

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Table 2. Hypothesis Testing Results for Schedule Productivity Levels

Test Days(h) Days(h)	Null hypothesis	Alternative hypothesis Days(h)	*P* 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

$$\text{P.I.} = \text{budgeted work hours}/\text{actual work hours}. \tag{1}$$

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 identify 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	*F*	*P*
Regression	2	1.52927	0.76464	41.81	0.000
Residual error	85	1.55436	0.01829	—	—
Total	87	3.08363	—	—	—

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Table 4. Hypothesis Testing Results for Overtime Model Predictor Variables

Coefficient tested	Null hypothesis	Alternative hypothesis	p 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

$$\mathbf{P.I.} = \mathbf{1.44} - \mathbf{2.2E}^{-7}{*}\mathbf{ActWrkHrs} - \mathbf{0.00947}^{*}\mathbf{Avg.Hrs/week} \tag{2}$$

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

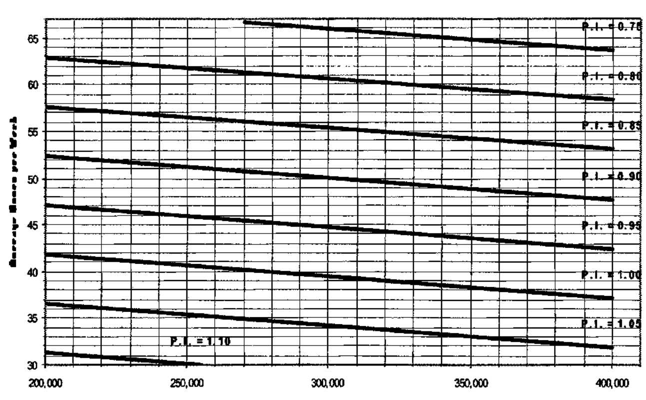

Fig. 2. Partial results of overtime model (200,000–400,000 actual work hours)

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

	Average hours per week							
	32	35	40	45	50	55	60	65
Actual work hours	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 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.

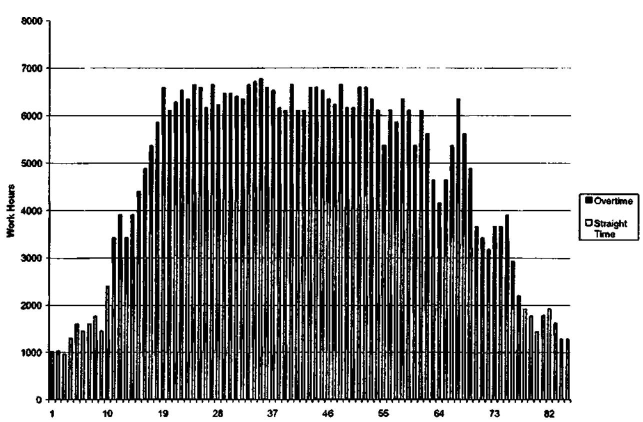

Fig. 3. Straight and overtime weekly work hours for application example project

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

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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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