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A Model for Assessing Maximum Overtime Rate in Labor Subcontracting Practices

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Abstract: Despite the rapid development in the construction industry due to the changing new technologies, many projects still fail to meet target deadlines. Shortage in manpower and skilled laborers is one of the main reasons for such delays. Markets with high economic growth and economic expansion (such as Gulf Countries in the Middle East) may have pronounced labor the shortages. Labor subcontracting practices are used sometimes to increase production rates and meet project deadlines. This paper explains and analyses labor subcontracting practices currently being used in many places around the world (and especially in the Gulf Countries) and in particular defines a maximum overtime rate for laborers in the laborer-subcontracting method ensuring that the contractor gains both the time saved during overtime and also reduces the cost per unit produced. The mathematical model used formalizes a closed-form equation for overtime pay in similar situations and as such can be applicable worldwide. Data was collected from representative projects that employed such practices from various trades. Validation of the model and formula has been tested successfully by analyzing historic data. The results prove that contractors often do not reach the optimum use of their practices resulting in a higher cost per unit. The presented model and the analysis should be of interest to many contractors currently involved in the practice or considering its use and to those who wish to find new methods that would help in eliminating as much wastes as possible by allocating their resources in the most efficient way.

Keywords: Productivity Improvement, Scheduling, Construction Project Management, Wages, Labor Relations

I. INTRODUCTION

Several studies such (BRT 1990, CII 1994, Hanna et al. 2005) suggest that the labor productivity in the construction industry has decreased in comparison to other industries especially in the last four decades in U.S.A. In contrary, the average hourly wage per man-hour work has increased. These studies show that the construction industry seriously lags other industries in controlling, developing and applying labor saving ideas. Furthermore, despite the rapid development within the construction industry and the high competencies, many projects still fail to meet target deadlines mainly due to shortages in manpower and skilled laborers. In the Middle East, particularly the U.A.E (United Arab Emirates); the situation might be worse. Statistics of the year 2006 portrayed the UAE as the region's top spender on construction projects with $294 billion worth of building work announced and being constructed - more than Bahrain, Qatar and Oman combined (Ditcham 2006) yet, many projects have failed in providing clients with a high service quality in terms of time and budget delivery. Simultaneously, more than 300,000 of the unauthorized laborers left the U.A.E. resulting in a 20% increase in the overall construction cost (Gulf News 2007). Furthermore, some trades, such as Masonry work, experienced more than a 50% increase in the overall construction cost (Gulf News 2007).

Scheduled overtime is defined as the planned employee overtime hours extended to complete a certain task, work package, or milestone, before a deadline. Scheduled overtime is often used to offset labor shortages. In the various literature studied, there seems to be no consensus on the effect of scheduled overtime in construction industry. Mayo et al (2001) concluded in their study that the overall average productivity increased when laborers worked limited scheduled overtime on a daily and weekly basis. In contrary, the Construction Industry Institute (CSI 1994), the Mechanical Contractor Association (MCAA 1994), Business Roundtable (BR 1990) and National Electrical Contractor Associations (NECA 1989) all found that individual employee productivity declined with overtime hours. This lack of consensus can be attributed to the fact that there are several other factors that affect productivity in scheduled overtime. Some of these factors are managerial factors associated with labors' superintendent such as planning and control, material movement, crew interference, risk transfer and material management (Yun 2012, Hanna et al 2005, Thomas and Raynar 1997). According to Yun (2012), labor subcontracting in Korea follows a multi-layer hierarchy to transfer risk of supplying and management of labor to subcontractors. In this multi-layer hierarchy practice the general contractor gets the labor required through intermediaries or foremen.

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Then, the subcontractor outsources the labor to another contractor. In a survey conducted on building sites in Korea it was found that as many as five tiers of subcontracting may be exist and in 70% of the sites a three tiers of subcontracting were realized.

The practice of scheduled overtime in the U.A.E. and several other countries around the world is entirely different from the ones studied in the previous literature cited above. In these situations, scheduled overtime is more appropriately dubbed "laborer subcontracting" as will be presented in the next section. This paper presents an analysis of the labor-subcontracting method and in particular defines a maximum overtime rate for laborers in the labor-subcontracting method to ensure that the contractor gains both the time saved during overtime and also reduces the cost per unit produced. The paper is defined into various sections: the first section analyzes the labor subcontracting method in more detail. This is followed by a mathematical model of the method which formally defines all the variables involved and extracts a closed-form term for the maximum acceptable overtime rate according to the based, paid and actual production rates. The final section includes an analysis of data demonstrated with a numerical example.

II. Labor-Subcontracting

For consistency purposes, production rate is defined as the number of output units per unit of time, e.g. 25 tons of steel per day. Productivity, on the other hand, is defined as the number of output units per man-hour of work, e.g. five tons per man-hour. In order to meet strict deadlines, it would be beneficial to sometimes increase the production rates of some activities. By increasing the production rate of repetitive tasks on the project schedule, one could decrease the duration of these tasks and hence may reduce the overall project duration. However due to the lack of construction laborers in many countries, increasing the production rate by increasing the resources assigned to project activities is usually not possible. Similarly, the amount of overtime work that can be carried out is limited by the hours of the day especially in the summer where the temperature frequently exceeds 120 degrees Fahrenheit. Increasing the productivity of the laborers itself, on the other hand, would result in a shorter duration and may even result in cost savings as will be discussed below.

TABLE I
Laborers' Production Rates for Fixing Steel Reinforcement Contracting Company in the U.A.E. (Data From Amana Steel Company, Dubai UAE, 2007 & 2008)

S.NO	Description	Manpower	Equipment	Unit	Output
a	Reinf. of Footing	1SF+ 1H		KG/ Day	300
b	Reinf. of Stub Column	1SF+ 1H		KG/ Day	200
c	Reinf. of Strap Beam	1SF+ 1H		KG/ Day	200
d	Reinf. of Tie Beam	1SF+ 1H		KG/ Day	200
e	Reinf. of wall	1SF+ 1H		KG/ Day	300
f	Reinf. of Column	1SF+ 1H		KG/ Day	300
g	Reinf. of Beam	1SF+ 1H		KG/ Day	200
h	Reinf. of Solid Slab	1SF+ 1H		KG/ Day	150
i	Reinf. of Lintel	1SF+ 1H		KG/ Day	150
j	Reinf. Copying beam 20x20cm	1SF+ 1H		KG/ Day	200
k	Reinf. of Parapet	1SF+ 1H		KG/ Day	150
l	Reinf. of Arch Lintel	1SF+ 1H		KG/ Day	250
m	Reinf. of Staircase				
n	Mesh. Reninforcement	1SF+ 2H		M2/ Day	250

SF = Steel Fixer, H = Helper

In the Gulf countries, the construction industry runs six days a week. Laborers have to work eight hours per day and any work beyond these hours is considered as overtime. Laborers are expected to meet set production rates. The basic production rates of each trade will vary depending on the trade itself, company's profile and labor experience. Each company has its own base production rates for the various trades and for the various tasks involved. For example, table 1 shows expected production rates for fixing steel reinforcement for a large contractor in the UAE.

The production rates shown in table 1 are used as a basis for paying the laborers and are also used in preparation of cost and time estimates. These base rates are usually conservative and are usually easily achievable by the laborers. Due to the low wages in the construction industry, most companies will let their laborers work for more than eight hours a day assuring that the minimum planned production rates are achieved. Most likely, engineers do not plan the overtime hours unless their projects are lagging behind the planned schedule. In such a case, the overtime hours will be offered to the laborers on a lump sum basis. In other words, laborers are offered a lump sum amount (which translates to extra hours by dividing it by the hourly rate) given that the laborers (as a crew) meet a specific deadline. The lump sum scheduled overtime might be given on a daily or weekly basis depending on the task, the number of laborers assigned to do it and the person who is in charge of labors productivity such as engineers, engineer assistants or foremen.

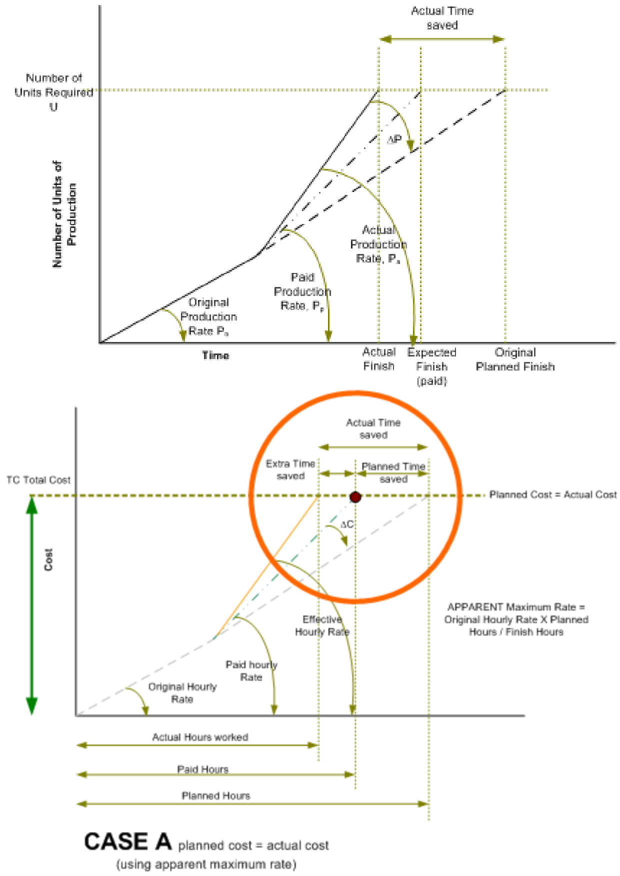

FIGURE I
THE RELATIONSHIP BETWEEN THE ORIGINAL (BASE), PAID AND ACTUAL PRODUCTION RATES

The lump sum scheduled overtime hours will almost all the time result in a significant increase in laborers' productivity. The increase in labor productivity usually happens because of the two following facts; the first reason is that base production rates are usually very conservative and are often under estimated as clearly realized from the figures shown in Table 1; second the main goal of the laborers when working overtime using this method is to meet the set amount of work to be done (output units of work) allowing laborers to stop the work once they have achieved their assigned work quotas regardless of the time they actually take. Therefore, as soon as laborers finish their tasks they are free to leave and the overtime hours which have been assigned to them on a lump sum basis will be paid. The subcontracted monetary amount (i.e. the new overtime hours paid) is usually set by the project manager based solely on experience and judgment. This practice is employed extensively on large projects. Significant improvements to the practice can be made by developing a rigorous method for setting an upper limit on the amount of overtime paid. This fact creates an interesting situation, where the paid hourly rate is lower than the actual effective hourly rate as will be described next.

III. MATHEMATICAL MODEL FOR LABOR-SUBCONTRACTING

The relationship between the original (base), paid and actual production rates is shown in figure 1. The base production rate is based on the original base case such as those shown in Table 1 which is based on a conservative estimate of labor productivity, while the actual production rates are the ones actually achieved with the increased labor productivity. The paid production rate is the equivalent rate on which the lump sum amount is determined. The initial assumption of the labor subcontracting method is that the base productivity is lower than the paid productivity. Furthermore the actual productivity achieved by the laborers is higher than the one they are paid based on, i.e., $P_b \le P_p \le P_a$. In the discussion of the next section the following notations are used:

Co = cost per man hour for overtime
Cb = cost per man hour for base-case
UCo = cost per unit for overtime
UCb = cost per unit for base-case+
Pb = base productivity
Pa = actual productivity
Pp = paid productivity
U = Units
Hb = man hours taken to produce U units using the base productivity
Ha = man hours taken to produce U units using the actual productivity
Hp = man hours taken to produce U units using the paid productivity

The idea is to compare the cost per unit in the base case and compare it with cost per unit in the overtime case. The cost per unit in the base case can be given by dividing the total cost for producing the units by the number of units (U). The total cost for producing the U units is in turn equal to the number of man hours it takes to produce the U units, Hb, times the cost per man-hour. Therefore the cost per unit in the base case is,

$$UC_b = \frac{C_b \times H_b}{U} \quad (1)$$

Also given the base productivity, Pb, one can determine the number of hours it should take to produce these, U units,

$$P_b = \frac{U}{H_b} \therefore H_b = \frac{U}{P_b} \quad (2)$$

Substituting in (1), we get cost per unit in the base in terms of the base productivity as,

$$UC_b = \frac{C_b \times \left(\frac{U}{P_b}\right)}{U} = \frac{C_b}{P_b} \quad (3)$$

Now one needs to determine the cost per unit in the overtime case to compare with that of equation 3. The unit cost in the overtime case can be given by,

$$UC_o = \frac{C_o \times H_p}{U} \quad (4)$$

In the overtime case however, it is important to note that the laborers are paid based on an assumed productivity (Pp) that is in fact usually lower than their actual productivity (Pa>=Pb). In that case, it is easy to see that the cost per unit in the overtime case, UCo, will therefore be higher than the cost per unit in the base case, UCo>=UCb. To determine the cost per man-hour in the overtime case, Co, the total cost of producing the U units using overtime is divided by the actual hours worked. The total cost of producing the U units using overtime can in turn be calculated by multiplying the cost per man-hour (which is the same as in the base case) by the hours taken to produce U units assuming the paid productivity Hp, i.e. the productivity that the laborers are paid if they work overtime, (Pp). Therefore the cost per man-hour in the overtime case is given by,

$$C_o = \frac{H_p \times C_b}{H_a} \quad (5)$$

Therefore one can see that the cost per man-hour in the overtime case, Co, will therefore be higher than the cost per man-hour in the base case since the laborers will finish the same U units in Ha hours, which is less than the Hp hours they are paid for (because $P_a \geq P_b$). Also, since $P_p = U/H_p$ and $P_a = U/H_a$ equation 5 can be also written as,

$$C_o = \frac{P_a \times C_b}{P_p} \quad (6)$$

Substituting equation 6 in 4 we get,

$$UC_o = \frac{\left(\frac{P_a \times C_b}{P_p}\right) \times H_p}{U} \quad (7)$$

From equation 6, we can state that the ratio of the base hourly cost to the overtime hourly cost is the same as the ratio between the actual productivity and the paid productivity, $\frac{C_o}{C_b} = \frac{P_a}{P_p}$

This points out to an interesting paradox. As the actual productivity increases in relation to the paid productivity, the time it takes to produce the same U units will decrease and therefore the cost per man-hour will increase. However that is not the entire picture since the determinant of whether to use overtime in that case is the cost per unit, UCo and UCb, rather than the hourly cost. What is needed now is to determine the relationship between the three kinds of productivity involved: (1) Base productivity, (2) Paid productivity and (3) Actual productivity. In other words, it is important to understand what the minimum paid productivity is needed for to save time and money.

Substituting equation 2 in 7 we get,

$$UC_o = \frac{\left(\frac{P_a \times C_b}{P_p}\right) \times H_p}{U} = \frac{\left(\frac{P_a \times C_b}{P_p}\right) \times \frac{U}{P_p}}{U} = \frac{P_a \times C_b}{(P_p)^2} \quad (8)$$

Since one of the initial assumptions of the labor subcontracting method is that the actual productivity is higher than the base productivity, it is clear that the contractor is going to save time by working overtime. However in order for the contractor to save money as well, the cost per unit for overtime has to be lower than the cost per unit in the base case, i.e.

$$UC_b \geq UC_o \quad (9)$$

Substituting equations 3 and 8 into equation 9 above we get that,

$$\frac{C_b}{P_b} \geq \frac{P_a \times C_b}{(P_p)^2} \quad (10)$$

i.e.,

$$P_b \geq \frac{(P_p)^2}{P_a} \quad (10)$$

or,

$$P_p \leq \sqrt{P_a \times P_b} \quad (11)$$

In the case where the laborers' actual productivity is equal to the one they are paid based on (i.e. $P_a = P_p$), then equation 10 will be simplified to $P_b \leq P_p$. This simply states that if the actual productivity of the laborers (which is the same as the one they are paid based on) is higher than the base productivity then the contractor will save time and money over the base productivity case. Consequently, equation 11 can be expressed as $P_p \leq \sqrt{P_p \times P_b}$. The various possible cases are shown in Figure 2. The three cases show different outcomes in terms of the time saved and the amount paid per unit of work. In the first case the contractor can save time and pay the same amount per unit. In the second case the contractor saves time but ends up paying more per unit and in the third case the contractor saves time and pays less per unit. The main factor affecting each outcome is how much money is offered in lump sum to the laborers. The important feature here is that the upper limit on the lump sum amount offered to the labors depends on both the base productivity and their actual productivity, which can only be determined by analyzing historic data as shown in the next section.

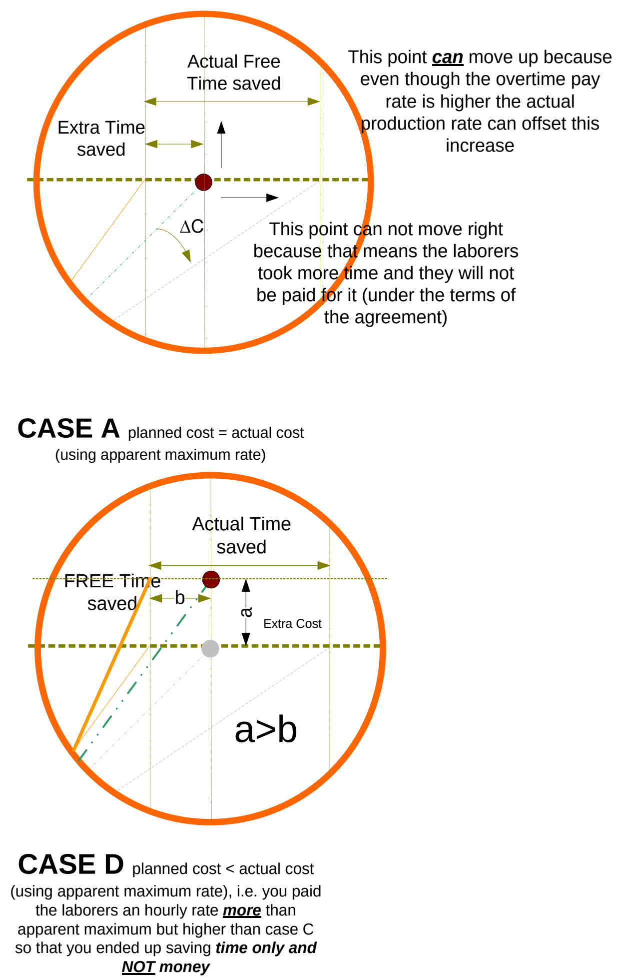

FIGURE II
POSSIBLE CASES FOR BASE, PAID AND ACTUAL PRODUCTION RATES

IV. DATA COLLECTION

In order to effectively utilize equation 11, we need to define a relationship between the actual productivity and the paid productivity. The base productivity is usually set by the company a-priori. In general however, as the paid productivity increases the laborers will have a higher incentive to complete the job faster, since their hourly cost increases proportionally, and they would be driven to complete the job faster in order to start on possible new jobs. It is reasonable therefore to assume that as the paid productivity increases, the actual productivity will also increase subject to specific constraints. In order to accurately study this relationship, historic data from company records of two major contractors who regularly practice laborer subcontracting in the UAE was analyzed (AMANA and TWAM). Historic data was collected from these companies for three major work items; solid slab steel reinforcement, interlock tile installation and painting. Specific tasks related to the various three work items were selected from the schedules of historic projects. A total of forty eight (twenty three from AMANA and twenty five from TWAM) previous projects were analyzed and task information related to the three major work items were extracted. Data collected included the base pay rate and overtime base rate as well as the planned and actual activity durations. Tasks that were of the same type and sequential were concatenated into one, while tasks of the same type that had separate start and end dates were considered separately. These activities were chosen for analysis because they are typical candidates for labor subcontracting and data for them was readily available. These activities also usually appear as distinct activities in the schedule and therefore the effect of labor subcontracting can be easily analyzed.

The forty eight projects were of various sizes and covered a wide range of project type and size (Table 2). However, the chosen projects were mostly projects that were crashed and therefore laborer subcontracting was utilized extensively on these projects for various activities including the three activity types selected. All of the chosen three work items appeared in the schedules of the forty eight projects were analyzed multiple times. In many instances different paid productivities were used and therefore data existed for a large range of paid productivities versus actual productivities. The data collected included the duration which the laborer subcontracting was used (the duration of the overtime work).

As a first step, cost and duration data was converted to productivity data including the actual and paid productivity (the base productivity values were given from the standard forms for both of the companies considered). So for each work item a table was created that shows the paid productivity values versus the actual productivity values. Since the same paid productivity values were used by the project manager several times, multiple actual productivity data values existed for the same paid productivity. Table 3 shows a sample of the data collected for the slab steel reinforcement. Note that the paid productivity values represent centers of the data ranges. The table also shows how the actual productivity changes as a function of the duration of the overtime work which was calculated from the schedule as the difference between the start of overtime work and the end of the activity. For the steel reinforcement the paid productivity ranged from the base productivity of 200 kgs per day up to almost double the productivity (380 kgs per day). The duration of overtime work ranged from 4 days up to 15 days. The collected data showed that the laborer subcontracting method was rarely used for overtime duration below 4 days and the data for overtime durations of more than 15 days was scarce. Although some data points were not available from the data collected, a value for actual productivity was found for each corresponding value of paid productivity. Similar data was collected for the three other work items.

TABLE II
DATA ABOUT DIFFERENT PROJECT TYPES AND SIZES

No.	**Cost (AED)**	**Built-Up Area (m^2)**	**Duration (month)**	**Year Completed**	**Floors**
1	10556952	16044	156	2003	12
2	5627400	13560	156	2003	12
3	8871588	17193	154	2004	11
4	7729461	12861	99	2003	9
5	7926480	18180	110	2003	10
6	4793580	8910	108	2003	9
7	15278256	23724	180	2003	12
8	3665664	8256	104	2003	8
9	4984100	9850	110	2003	10
10	7496874	12474	154	2004	11
11	8331048	20724	144	2004	12
12	10168140	14844	168	NA	12
13	6931352	11768	120	2003	8
14	8023554	14886	117	2003	9
15	3722643	7551	99	2004	9
16	4243200	6528	88	2003	8
17	9004300	14180	150	2003	10
18	8223376	13328	98	2004	7
19	6440000	11200	84	2004	7
20	5084585	10615	165	2003	11
21	7179480	10360	91	2003	7
22	8303680	13480	120	2003	10
23	7277085	16353	117	2004	9
24	6926304	11244	168	2004	12
25	10373506	20999	165	2004	11
26	11028960	15984	156	2003	12
27	7858377	17739	108	2003	9
28	12561948	19908	156	NA	12
29	7657650	13650	105	2003	7
30	4813848	10008	144	2004	12
31	8695890	16254	126	2003	9
32	8057961	16893	126	2003	9
33	10582180	18340	110	2004	10
34	4243456	8288	77	2004	7
35	12299947	19129	143	2003	11
36	6585520	12520	140	2003	10
37	13529520	23736	144	2004	12
38	5560578	12141	117	2004	9
39	5109720	10780	132	2003	11
40	6764160	13008	168	2003	12
41	9625952	14032	104	2004	8
42	5971020	14388	154	2003	11
43	7095144	11298	98	2004	7
44	4837113	11223	99	2004	9
45	6084432	12267	108	2003	9
46	9972690	19670	150	2003	10
47	10318560	19920	150	2004	10
48	14493240	22824	132	2004	12

TABLE III
SAMPLE DATA COLLECTED FOR THE SLAB STEEL REINFORCEMENT

		Actual Productivity - Steel Solid Slab Reinforcement (Kgs per day)									
		Days of overtime (working days)									
	Paid Productivity	4					5			6	
No.	Kgs per day	Value 1	Value 2	Value 3	Value 4	…..	Value 1	Value 2	…..	Value 1	
1	200.0	187.0	328.6	490.1	NA	…..	180.2	171.1	…..	171.3	..
2	210.0	202.1	452.1	NA	491.0	…..	NA	197.3	…..	175.0	
3	220.0	NA	NA	406.0	NA	…..	244.4	NA	…..	NA	
4	230.0	272.8	391.6	437.0	474.5	…..	NA	NA	…..	236.6	
5	240.0	279.0	335.1	NA	5191.2	…..	274.2	249.7	…..	NA	
6	250.0	NA	327.6	377.0	NA	…..	283.7	NA	…..	281.0	
7	260.0	271.2	NA	363.8	NA	…..	NA	245.0	…..	245.7	

8	270.0	299.2	354.3	395.9	NA	…..	288.5	NA	…..	NA
9	280.0	333.2	374.5	NA	NA	…..	NA	310.5	…..	291.0
10	290.0	NA	NA	314.6	NA	…..	294.3	NA	…..	283.7
11	300.0	333.9	334.5	297.8	NA	…..	NA	326.4	…..	312.7
12	310.0	NA	352.7	NA	NA	…..	NA	NA	…..	271.9
13	320.0	333.4	NA	NA	NA	…..	311.5	327.3	…..	NA
14	330.0	370.7	463.1	NA	577.3	…..	NA	NA	…..	330.0
15	340.0	NA	368.9	NA	539.8	…..	293.3	310.5	…..	NA
16	350.0	423.6	NA	577.9	NA	…..	399.7	395.6	…..	NA
17	360.0	NA	NA	NA	NA	…..	382.5	NA	…..	NA
18	370.0	NA	NA	444.1	426.9	…..	NA	NA	…..	NA
19	380.0	NA	NA	NA	561.8	…..	NA	330.1	…..	NA

V. Data Analysis

The actual productivity values were averaged for each value of paid productivity and by the overtime duration. This was carried out for the three work items chosen. Figures 3 to 5, show a plot of the paid versus actual data for the three work items in the cases where overtime work was used up to durations of 4 days. Although the relationship between paid and actual productivity is different for different work items, the general trend found in the data is similar. The figures show that for the three work items analyzed, as the paid productivity increases the actual productivity achieved by the laborers also increases up to a certain limit. For clarity in figure 3, the secondary axis shows the ratio of actual to paid productivity (data was normalized as a percentage of the base productivities to uniformly assess the effect of paid productivity on actual productivity).

Linear and non-linear single variable regression analysis was carried out first to test the effect of paid productivity versus actual productivity. A linear model would result in $P_p \le \sqrt{m \times P_p \times P_b}$, where m is a constant that depends on the type of task to be carried out. However linear regression for the different work items showed low r-squared values (e.g. 0.562 for the steel reinforcement tasks).

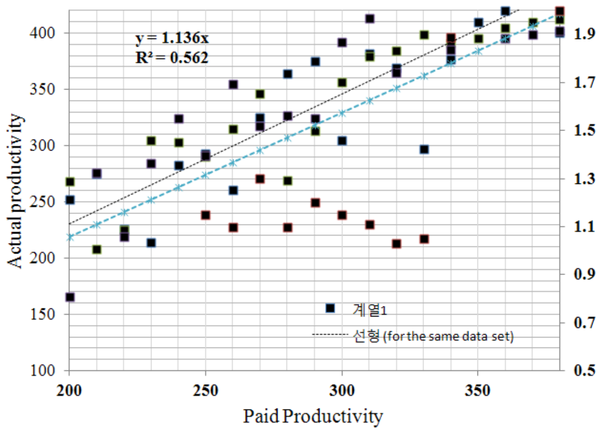

FIGURE III
PAID VERSUS ACTUAL PRODUCTIVITY FOR 4 DAYS OVERTIME DURATION OF THE SLAB STEEL REINFORCEMENT TASKS

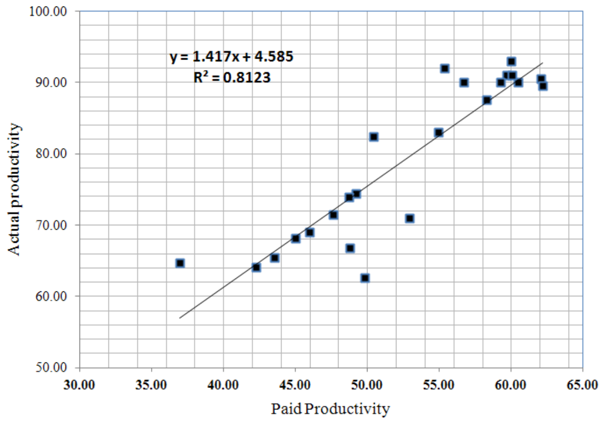

FIGURE IV
PAID VERSUS ACTUAL PRODUCTIVITY FOR 4 DAYS OVERTIME DURATION OF THE INTERLOCK TILE INSTALLATION TASKS

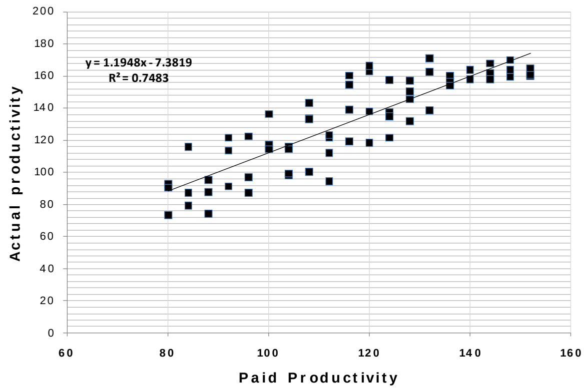

FIGURE V
PAID VERSUS ACTUAL PRODUCTIVITY FOR 4 DAYS OVERTIME DURATION OF PAINTING TASKS

Therefore, various nonlinear functions were tested including the exponential functions, logarithmic functions, trigonometric functions, power functions, Gaussian functions, and Lorentzian curves.

An exponential function in the form of $P_a = P_p^{\alpha}, P_p < c$ where α = 0.11, showed an r-squared of 0.681 for the same data set of the slab steel reinforcement tasks and is plotted in figure 3. This would mean that equation 11 can be written as $P_p \le P_b^{\left(\frac{1}{1-\alpha}\right)}, P_p < c$.

None of the non-linear models could accurately model the relationship between the paid and actual productivity values. At this stage it is important to note that there is an upper limit for the relation between paid and actual productivity. The data for the three work items analyzed shows that the increase in actual productivity versus paid productivity holds true until a certain critical point, where the laborers have reached their physical limit and are no longer able to increase their productivity further (Figures 3, 4 and, 5). The actual productivity values around this critical point seem to hold steady even with an increase in the paid productivity. Therefore the data seems to have formed two clusters, one at or below a critical maximum achievable productivity and another cluster beyond that critical point. After removing outliers, a clustering analysis was carried out to determine the cut off value. A k-means algorithm was used where initial means for k clusters were selected. The dissimilarity between the data points and the mean of a cluster were calculated, the data points were allocated to the cluster whose mean is nearest and then the mean of a cluster from the data points allocated to it is recalculated so that the intra cluster dissimilarity is minimized. This was repeatedly performed until the algorithm converged. The results of the clustering analysis for the slab steel reinforcement tasks with a 4 day overtime duration is shown in figure 6. Two distinct clusters are shown in figure 6 and most of the data sets for the various tasks and overtime durations also show similar trends. This showed that there is a clear upper limit that the productivity can reach even with a concurrent increase in pay.

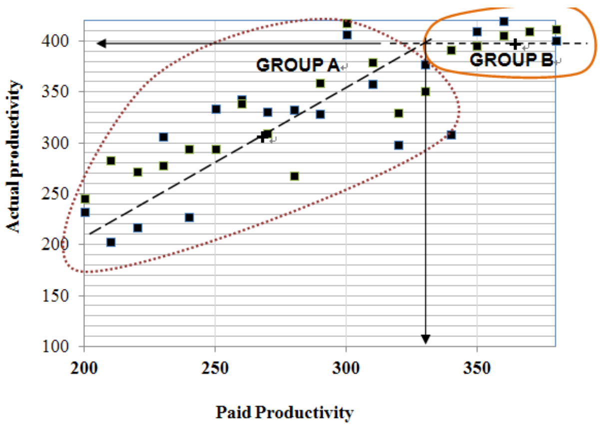

FIGURE VI
CLUSTERING OF PAID VERSUS ACTUAL PRODUCTIVITY VALUES FOR 4 DAYS OVERTIME DURATION FOR THE SLAB STEEL REINFORCEMENT TASKS

In order to develop an overall model for upper limit on paid productivity, segmented regression was used to determine the upper limit. In this approach the independent variable (paid productivity) was partitioned into 2 intervals and a separate line segment is fit to each interval. In particular we used segmented linear regression whereby the relations in the intervals were obtained by linear regression. This approach was able to model an upper limit of productivity as well as quantify the relationship between the paid and actual productivity in one overall model. The breakpoint can be interpreted as a critical, threshold value beyond which there is no reason to increase the paid productivity value. This breakpoint is important in decision making for contractors. Therefore, equation 11 could now be expressed as $P_p \leq \sqrt{m \times P_p \times P_b}, P_p < P_{\max}$ or simply $P_p \leq m \times P_b, P_p < c$, where m and $P_{\max}$ are constants that depends on the type of task to be carried out. Note that $P_{\max}$ is an upper limit for the regression. As an example, consider the data for the slab steel reinforcement tasks shown in figure 6 and by applying segmented linear regression, it was found that $P_{\max} = 397$ achieved at a paid productivity of 331, which represents the break point. Assuming a zero intercept (which is logical since a zero paid productivity would yield a zero actual productivity), the constant of regression for the two segments were found to be 1.45, and 0.11 resulting in an r-squared values of 0.435 (significant) and 0.395 (significant).

VI. ACTUAL/PAID PRODUCTIVITY MODEL DEVELOPMENT AND TESTING

In order to reach a single quick check on the payment made to the laborers, we need to combine the upper limit $P_{\max}$ and the rest of the data in one mathematical model. Therefore the logistic (or sigmoid function) could be used. The logistic model showed a good fit for all the data sets described above (r-squared above 0.8 for all 3 data sets) and more important it is able to model the behavior of paid and actual productivity values by including the $P_{\max}$ in a single model in the form of,

$$P_a = \frac{P_{\max} \times e^{\alpha P_p}}{P_{\max} + e^{\alpha P_p}} \tag{12}$$

Where Pmax is the maximum achievable productivity, which is determined from the segmented linear regression performed above and α is constant signifying the relationship between the paid and actual productivity up to Pmax. This equation states that the actual productivity will increase in relation to the paid productivity and also as a function of the initial base productivity at an exponential rate up to a certain value Pmax, where any increase in the pay will not result in an increase in productivity and therefore equation 11 now becomes,

$$P_p \leq \frac{\sqrt{P_b} \times \sqrt{P_{\max}} \times e^{\frac{\alpha P_p}{2}}}{e^{\frac{\alpha P_p}{2}} + \sqrt{P_{\max}}} \tag{13}$$

This equation sets an upper limit on the paid productivity Pp so that the contractor saves time and money in terms of unit cost and can be checked using an iterative method since Pp appears on both sides. Once the Pmax and α have been determined using the regression technique discussed above, Equation 13 then can be used as a quick check on the amount of extra pay given to the laborers to ensure optimum return for the contractor on the extra payment made to the laborers. Note that this equation does not set the paid productivity value, but instead sets an upper limit on that amount. This is important because depending on the project conditions, the need to reach certain actual productivities will vary. For instance depending on how much crashing is required in the project, contractors can increase the paid productivity value but have to always ensure that the condition of equation 13 is satisfied. A natural extension of this work would be to tie equation 13 to a cost-time tradeoff analysis which will be a function of the specific project conditions.

Figure 7 shows a plot of the model for various overtime durations. Each of the curves shown is plotted for certain overtime durations as marked on the figure. The data is plotted as percent increase from base productivity. It is important to note that beyond Pmax the amount of work to be carried out becomes a factor. When the amount of work scheduled in overtime is extensive, the laborers are required to work for extended amount of times and their actual productivity starts to drop. However, for relatively short durations of overtime, the laborers are able to maintain their maximum productivity. Therefore there is another critical value and this is the critical quantity of work to be carried out during overtime beyond which the productivity of the laborers starts to drop. This second critical quantity depends on the nature of each task. The duration of overtime work actually represents the third dimension in the proposed model. Rather than developing a surface regression for the data, the authors recommend developing a set of α values for the various ranges of unit item work quantities (which translates to the overtime duration worked). For example for the slab steel reinforcement tasks and with an overtime duration of up to 4, 8 and 12 days, the α value would be 0.69, 0.76 and, 0.80. Therefore, given a certain task, the base productivity value and the amount of work measured in units (this corresponds to the duration of overtime expected), the model can predict the actual productivity achievable and in turn set an upper limit on the laborer subcontracted amount.

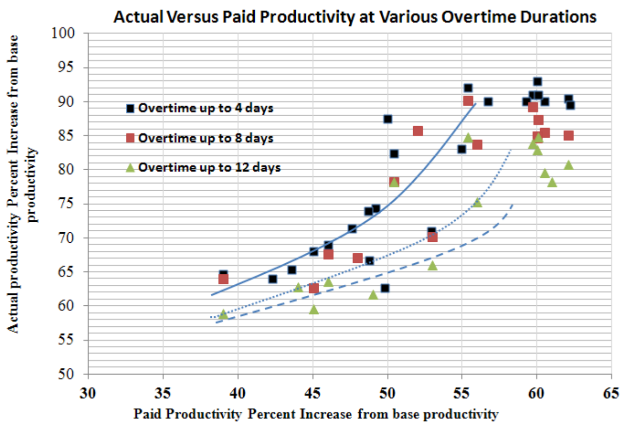

FIGURE VII
PAID VERSUS ACTUAL PRODUCTIVITY CURVES FOR 4, 8 AND 12 DAYS OF OVERTIME FOR THE SLAB STEEL REINFORCEMENT TASKS USING THE LOGISTIC MODEL

A practical application of the model would be to calculate the amount of money that would have been saved if the model had been used in the 48 projects collected. This entails calculating the upper limit on the paid productivities in each case and comparing it to the real paid productivity. In cases where this upper limit is exceeded, the contractor had saved time but had actually paid more in terms of unit cost. This may or may not be justifiable depending on the crashed duration. The question that the model can answer is: could the contractor have achieved the same crashed duration with a lower paid productivity? In those cases where a lower paid productivity could have achieved the same duration, how much money could have been saved and based on the statistical confidence interval of the proposed model, one can estimate a range for the money that could have been saved. This analysis was carried out for the slab steel reinforcement tasks only and with a model confidence interval of 90%, the contractor could have saved between 23,234 AED (United Arab Dirhams) and 35,456 AED on average per project (for the 48 projects) selected. Although this amount seems low (between around $5500 and $7500), This saving is for a single task only and would add up to a significant amount if the model is developed and used for all the activities that could be laborer subcontracted. In addition, the savings would be even more if one considered the entire portfolio of projects performed by the contractor.

VII. CONCLUSION AND RECOMMENDATIONS

This paper presented a model for the labor subcontracting method, which is widely practiced in many countries especially in the Gulf area to meet schedule deadlines. The method has involved paying laborers a lump sum amount to meet a compressed schedule by working overtime hours. The practice was analyzed and closed form equations were derived to limit the amount of lump sum values offered to the laborers to ensure that the contractor can save both time and money. Data was collected from representative projects that employed such practices from various trades. Validation of the model has been tested successfully by analyzing historic data. A logistic model was suggested to predict the actual productivities and to set an upper limit on the paid productivity. An interesting result is concluded when the proposed model is applied to the previous project tasks and compared with actual collected data. The results show that contractors often do not make the optimum use of the laborer subcontracting practice which results in a higher cost per unit.

It is important to note that this practice is based on a set of assumptions which may not be valid in all cases. The most important assumption is that the initial productivities, based on which the laborers get paid, are conservatively set. This in effect makes this method applicable when the laborers are paid daily rates and required to meet certain production quotes. Other aspects of the practice such ethical, managerial and socio-political aspects are not discussed and deserve more attention in future research.

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