KICEM Journal of Construction Engineering and Project Management
Online ISSN 2233-9582

www.jcepm.org
http://dx.doi.org/10.6106/JCEPM.2015.5.1.040

The Productivity Improvement for Steel Framing Work Efficiency by Work Sampling and 5-minute Rating Technique

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Abstract: This study presents the results of our analysis and recommendations for process and productivity improvements. The project studied consists of a 5-story research building, with a structure of steel frames supporting concrete slabs. The observations focused on the analysis of the overall erection and framing process. The methods used for the analysis consisted in intensive visits on site, where construction processes were observed in term of resources, activities, durations, materials' handling procedures, and technology used. Back to the office, authors used the information captured to model the different trades' activities, using work sampling and 5-minute rating technique. The work sampling provides insight into the activity, hence allowing for process improvements. The productivity of various trades is strongly dependent on the organization of the work process and work site conditions. Improving the productivity of the entire project or company is not possible until everyone is committed to improvement.

Keywords: Productivity, Work Sampling, 5-minute Rating Technique, Crew Balance Chart

I. INTRODUCTION

In manufacturing, output is measured in discrete physical units, and inputs include all labor, capital, and resources necessary to produce outputs. In the construction arena, however, there are both products and services involved, resulting in a variety of measurable units, such as linear feet, hours, physical spaces, and pages of graphics. Productivity is defined by economists as the dollars of output per worker-hour of labor input. But productivity is far more than a labor issue. Better tools and equipment, use of innovative materials, improved education, and training, and ideal weather conditions can all contribute to increased productivity [1].

For the efficient project, improving materials management and labor productivity are primary ways of increasing output. Labor productivity is a favorite topic among project managers. Continued improvements in labor productivity are possible through efforts of management with the cooperation of labor. A project manager should be aware of the productivity improvements can be replicated or continued on subsequent projects. Worker motivation and commitment directly affect the quality and speed of work at the site. To improve labor productivity, a number of steps can be taken [2].

The purpose of this study is to study a direct work activity at a construction site through a variety of work sampling methods, in order to identify opportunities to improve productivity. Intensive efforts have been made to analyze the process as a whole and the crew's productivity mainly by work sampling. The data gathered through these

Methods was then analyzed and compiled into several graphic illustrations to demonstrate the stages of the work process and crew productivity. After the specific operations the authors have focused on have been selected, the current state of the operation and analysis of the operation have been thoroughly investigated. Finally, recommendations to improve both the process and crew productivity have been suggested.

The study offers commentary on methods that might be employed to reduce waste in the process and improve productivity.

II. STUDY APPROACH

The study approach involved observations and on-site interviews. Authors took some pictures and monitored, when the elaborated work was taking place. From the observation, the activity duration times could be measured and the crew balance charts and Work Sampling were able to be created. From the interviews with project managers, authors established the crew usage information, subcontractor relations and information work thus far.

A. Work Sampling

Work sampling consists of a large number of observations taken at random intervals [3]. This definition provides a very clear idea of what work sampling all about. First, randomness is required to undertake work sampling based on statistical methods as follows:

- Any given instant of time has an equal likelihood of selection.
- There is no apparent order to the time of observation.
- One time observation is independent of all other times of observations.

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Then, the three major categories of classification that most widely used are effective work, essential contribution work, and ineffective work.

1) Effective work: Effective work is defined as place, align, force, and tie into position plus those elements that contribute directly to completing the unit of work. In the real world, there is no project that can have 100% effective work. This implies no perfect project in the real world. Generally speaking, the percentage of effective work in a project is various from 50% to 20% which depends upon project type and management.

2) Essential contributory work: Essential contributory work is the work that does not directly add to but essentially needed to finish the work unit. Commonly this includes five categories:

- Obtain or transport tools and materials with immediate vicinity of work area
- Receive/Give instructions
- Read drawings
- Cranes deliveries
- Minor contributory work

3) Ineffective work: Ineffective work is defined as doing nothing or doing something that is not necessary to complete the end product. Traveling with empty-handed and waiting is usually considered parts of ineffective work. As long as some specific work is not contributing to the end product, it is considered as ineffective work [4].

B. Project Description

The project is a 5-story steel structure building planned for communication center for local society. The analyzed operation is steel erection and framing, and the whole project is currently on schedule.

The selected area is located on the 4th floor where the materials are being lifted and carried by a mobile crane and then laid down with the assistance of workers. The steel members are delivered pre-fabricated on trucks. On-site the crane takes them off the truck onto the stock area. All structural metal framings are prefabricates off-site and delivered to the site stock area.

Crane coordination occurs at weekly subcontractor meeting. The unloading of steel members usually begins at 6 a.m. so that they have sole use of the crane before other subcontractors show up to work.

III. DATA GATHERING

A. Site Visit

An initial site visit must be deployed for gaining related documents, such as specifications, schedules, drawings, photographs, etc, before the study could be completed. Observing the activities, speaking to the superintendent for requesting related information, and taking photos for understanding of the construction project are with the purposes of having preliminary information. All surveyors visited the job site, worked on observing the crew, took some photos, etc. Final data collection and analysis, composition of each major subjects (work sampling and 5-mintute rating technique), and summary/conclusions /discussions shown as follows will be assigned to surveyors one-by-one.

The crew contains 6 workers. The reasons that this work sampling study chose are that, first, the steel erection crew is the one that the study focused on since the selected construction site is under construction of its frame which consists of steel erection activities mainly. The other one is labor intensiveness where 6 workers in the sample project are easily to be observed.

The observations associated with the work sampling study were performed over 2-hour periods. The observations were done between 8:00 am and 10:00 am on 1st day, and 10:00 am to 12:00pm on 2nd day. The weather conditions on these two days were sunny, 52 oF on 1st day and overcast, 56 oF on 2nd day. No apparent impact appeared on the performance on these days.

B. Activity Classification

All the categories and involved activities are classified as TABLE I below.

TABLE I
ACTIVITY CLASSIFICATION

Category	Activity
Effective Work	Direct work
Essential Contributory Work	1. Obtain/transport material within area 2. Give/receive instructions 3. Direct crane operators 4. Field assembly 5. Touch-up painting 6. Loose lintels 7. Temporary shoring and bracing 8. Other minor contribution work
Ineffective Work	1. Travel empty handed 2. Obtain/transport material outside 3. Unexplained idleness or waiting 4. Waiting for material/instructions 5. Waiting for another craft 6. Authorized rest breaks 7. Weather/emergency delay 8. Delay caused by Crane 9. No contact

The following formula [Eq. (1)] was used to compute the number of random observations for this study:

$$N = \frac{K^2 P(1-P)}{S^2} \quad \text{Eq. (1)}$$

- N= Number of observation required
- P= Decimal equivalent of the percentage expected in a given category
- S= Decimal equivalent of the degree of accuracy
- K= Number of standard deviations required for a given confidence level

The P value is various. The direct work in this study was assumed to be 0.32 based on the average. This study would make S = 0.05 which implies the confident level in this study is 95%. For a 95% confident, K is equal to 1.96. Plug all above back to the formula [Eq. (1)]:

$$N = \frac{1.96^2 \times 0.32\ \times (1 - 0.32)}{0.05^2} = 334$$

The minimum of 334 observations are required based on a valid statistical assumption.

The result above showing that 334 observations are required, the following formula [Eq. (2)] can determine the number sample observations.

$$\frac{\#\,of\ observations}{\frac{5day \times 6observation}{Crew\ sample}} = Crew\ sample/day \qquad \text{Eq. (2)}$$

With 334 observations and 5-day-study period of 6-man crew, compute the Crew sample/day:

$$\frac{334}{5 \times 6} = 11.13\ \ Crew\ sample/day$$

$$11.13 \times 5 = 55.65\ \ \approx 56\ (Samples)$$

The sample form to collect and analyse the data for steel erection is as following TABLE II

TABLE II
OBSERVATION SHEET FOR STEEL ERECTION

Crew:	Crew Member:	
Assigned Location:		
Actual Location:		
Date:	Time:	Weather:
Observer:		

		Activity Category	Craftsman						Total	Comments
			1	2	3	4	5	6		
Eff.	1	Direct work								
Ess. Contributory Work	2	Obtain/transport mat'ls/tools within area								
	3	Give/receive instructions								
	4	Direct crane operators								
	5	Field Assembly								
	6	Touch-up painting								
	7	Loose lintels								
Ineffective Work	8	Temp. shoring and bracing								
	9	Other minor contribution work								
	10	Travel empty handed								
	11	Obtain/transport mat'l/tools outside								
	12	Unexplained idleness or waiting								
	13	Waiting for mat'l/tools/instructions								
	14	Waiting for another craft								
	15	Authorized rest breaks								
	16	Weather/emergency delay								
	17	Delay caused by Crane								
	18	No contact								

IV. DATA ANALYSIS

The collected data from the work sampling study are shown in Table III. The productivity rating obtained from the study is different from the “Productivity Ratings” applied to this trades in “Productivity in Construction [2]”.

TABLE III
COMPARISON OF PRODUCTIVITY
BETWEEN OBSERVED AND THE PREVIOUS STUDY
(Units: Productivity Ratings (Percent of Total Time))

	Effective	Contributory	Ineffective
Observed Productivity	18 %	42 %	40 %
Productivity in Construction [2]	36 %	33 %	31 %

The differences in productivity observed here are most likely due to the limited scope of the study. These industry-wide productivity ratings are based on a two-year study of a large contractor. No doubt, productivity by trades will vary significantly by task and work conditions. In this case, most of observations were limited to a stage of the work process in which workers were severely underutilized. For second reason for this difference, the work scooping could be considered. In structural framing activity, some contributory works, such as temporary shoring & bracing and touch-up paint, would rather be included in direct work. More significant studies of the complete form assembly process and the entire project site will be necessary to fairly evaluate project-level productivity.

Acknowledging that some degree of Contributory Work is necessary in any task, authors can analyze productivity in terms of the Labor Utilization Factor [3]:

Labor Utilization Factor

$$= \text{Effective Work} + \frac{1}{4} \times \text{Contributory Work} \quad \text{Eq. (3)}$$

Labor Utilization Factor

$$= 18.16\% + \frac{1}{4} \times (41.96\ \%)$$
$$= 29.09\ \%$$

The productivity ratings and Labor Utilization Factors offer good indications where process improvement is possible. As the current process exists, there is something to improve for the workers while they are performing the jobs. The key to improving productivity lies in improving the process itself.

TABLE IV
SUMMARY OF WORK SAMPLING RESULTS

Activity	# of Observations	Percentage
Direct work	**61**	**18.15**
Essential Contributory Work	**141**	**41.96**
Obtain/transport material within area	27	8.04
Give/receive instructions	1	0.30
Direct crane operators	45	13.39
Field assembly	18	5.36
Touch-up painting	25	7.44
Loose lintels	5	1.49
Temp. shoring and bracing	14	4.17
Other minor contribution work	6	1.79
Indirect Work	**134**	**39.88**
Travel empty handed	7	2.08
Obtain/transport material outside	13	3.87
Unexplained idleness or waiting	36	10.71
Waiting for material/instructions	18	5.36
Waiting for another craft	12	3.57
Authorized rest breaks	16	4.76
Weather/emergency delay	0	0
Delay caused by Crane	25	7.44
No contact	7	2.08
Total Sampling Work	**336**	**100**

A. *The 5-minute Rating Technique*

The 5-minute Rating Technique is a deterministic measurement technique employed to make a general assessment of the effectiveness of the crews. In this stage of study, the 5-minutes Rating Technique was applied to the case study project. In this method, the observer sums up the number of categorized observations to determine the effectiveness of the crews.

To obtain information for the study, the steel-framing workers at the case study project were observed at several intervals. In order to make sure that no hindrance is occurred, observation was carried at distance. Based on the observed data, the result of 5-Minutes Ratings on steel-framing workers is summarized as following [Eq. (4)].

$$\textit{Effectiveness ratio} = \frac{\textit{Sum of effective times for each individual crew member}}{\textit{The total time of observation}} \times 100 \quad \text{Eq. (4)}$$

In this study, it was observed that the structural metal framing workers in effective work activities 448 out of the total of 600 observations [TABLE V]. This is an effectiveness of about 74.67 % which gives us a total ineffective rate or delay of only 25.33 %. From these results, it could be concluded that there is somewhat to improve the workers’ efficiency in this trade.

TABLE V
SUMMARY OF 5-MINUTE RATING STUDY

	# Crews			# Crews			# Crews			# Crews			# Crews	
Time	Eff	In-eff	Time	Eff	In-eff	Time	Eff	In-eff	Time	Eff	In-eff	Time	Eff	In-eff
09:30:00	1	5	09:40:00	4	2	09:50:00	5	1	10:00:00	5	1	10:10:00	4	2
09:30:30	1	5	09:40:30	4	2	09:50:30	5	1	10:00:30	4	2	10:10:30	4	2
09:31:00	2	4	09:41:00	4	2	09:51:00	6	0	10:01:00	4	2	10:11:00	4	2
09:31:30	4	2	09:41:30	4	2	09:51:30	6	0	10:01:30	4	2	10:11:30	4	2
09:32:00	4	2	09:42:00	5	1	09:52:00	6	0	10:02:00	4	2	10:12:00	4	2
09:32:30	4	2	09:42:30	5	1	09:52:30	5	1	10:02:30	4	2	10:12:30	4	2
09:33:00	4	2	09:43:00	5	1	09:53:00	5	1	10:03:00	5	1	10:13:00	4	2
09:33:30	4	2	09:43:30	5	1	09:53:30	4	2	10:03:30	5	1	10:13:30	4	2
09:34:00	4	2	09:44:00	5	1	09:54:00	4	2	10:04:00	5	1	10:14:00	4	2
09:34:30	4	2	09:44:30	6	0	09:54:30	4	2	10:04:30	5	1	10:14:30	4	2
09:35:00	4	2	09:45:00	6	0	09:55:00	4	2	10:05:00	5	1	10:15:00	4	2
09:35:30	3	3	09:45:30	6	0	09:55:30	4	2	10:05:30	5	1	10:15:30	4	2
09:36:00	3	3	09:46:00	6	0	09:56:00	4	2	10:06:00	5	1	10:16:00	4	2
09:36:30	3	3	09:46:30	6	0	09:56:30	3	3	10:06:30	6	0	10:16:30	4	2
09:37:00	3	3	09:47:00	6	0	09:57:00	3	3	10:07:00	6	0	10:17:00	5	1
09:37:30	3	3	09:47:30	6	0	09:57:30	5	1	10:07:30	5	1	10:17:30	5	1
09:38:00	3	3	09:48:00	6	0	09:58:00	5	1	10:08:00	5	1	10:18:00	5	1
09:38:30	4	2	09:48:30	6	0	09:58:30	5	1	10:08:30	4	2	10:18:30	5	1
09:39:00	4	2	09:49:00	5	1	09:59:00	5	1	10:09:00	4	2	10:19:00	5	1
09:39:30	4	2	09:49:30	5	1	09:59:30	5	1	10:09:30	4	2	10:19:30	5	1
sub total	70	50	sub total	105	15	sub total	93	27	sub total	94	26	sub total	86	34
Effecti-veness	**58.3%**		**Effecti-veness**	**87.5%**		**Effecti-veness**	**77.5%**		**Effecti-veness**	**78.3%**		**Effecti-veness**	**71.7%**	

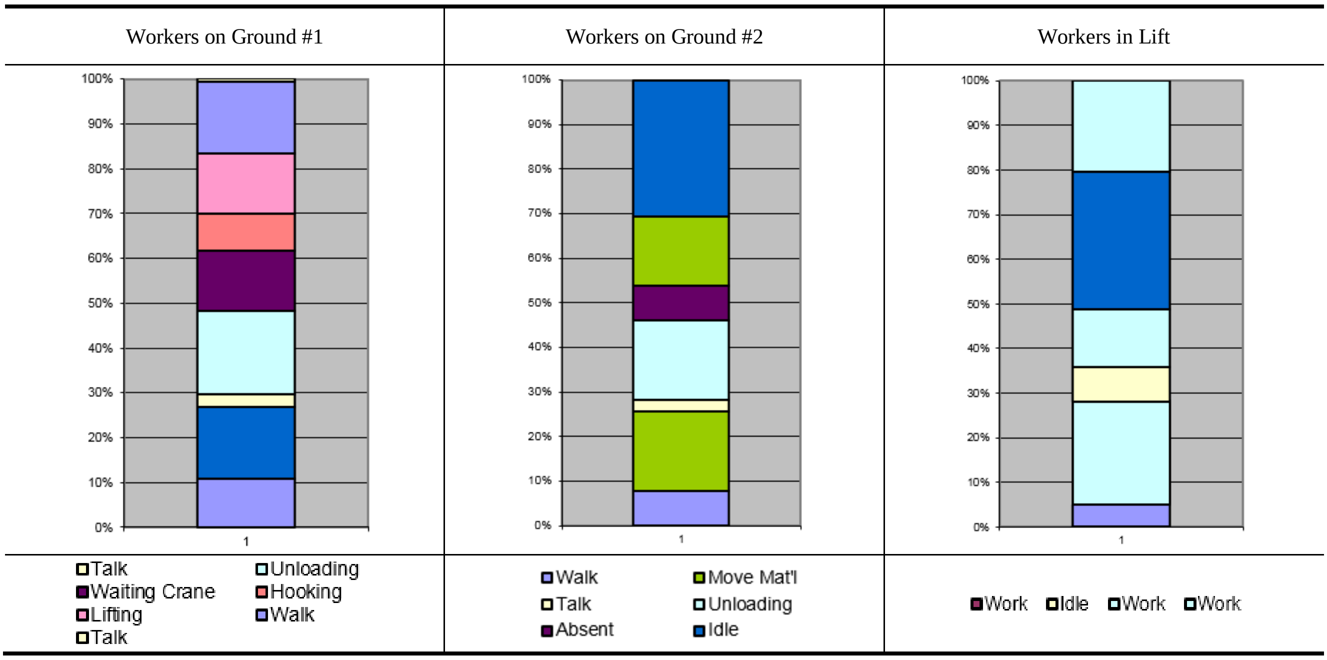

FIGURE I
Crew Balance Chart for Workers on Ground

V. RECOMMENDATION

A. Improvement by Crew Balance Charts

In short, there is much for the workers to do in this stage of the erecting and installing steel structural members. Refer to the Crew Balance Chart [FIGURE I]. Crews on the ground are really occupied with "busy work" while they wait for the foreman to notice them and gather other crews to lift and connect the steel members. They and other workers on site are frequently called away to various "Hey, you!" tasks on the project site (hence the absent time, when they left our observations).

Meanwhile, workers in the lift, who are installing steel members, are very efficient at this stage of the work process. The workers do not work at the same rate. For installing crews, most of their idle time is due to workers on the ground waiting to finish connecting members. This speaks to the importance of balancing crews for productivity whenever possible. Workers operating at the same pace (or a process that does not require them to work on the same piece of work together) might significantly reduce Ineffective Time. It also indicates one of the realities of construction: the Journeyman-Apprentice relationship common to most construction trades means that a crew will nearly always have some workers more productive than others. Short-term productivity gains must be balanced against the long-term need to have workers experienced and competent in a variety of tasks.

B. Increasing Precision of Off-Site Manufacturing

Increasing precision of "Off-site manufacturing" may also improve the total productivity. With much precisely manufactured steel members, or by applying the flexibilities, the contractor can eliminate work area overcrowding and incorporate better quality assurance into his product. When the crews are trying to install the structural steel members, they spent significant times adjusting the pre-fabricated off-site members. If the pre-fabricated materials were as accurate to suitable to on-site condition, it would result in significant improvements.

C. Safety

Several potential improvements could be suggested to process safety:

1) Site Cleanup and Overcrowding: The methods described above could significantly reduce the risk of tripping hazards and safety errors due to crew interference. If only one trade were working at any given time, there would be no hazards due to crews working at different elevations (i.e., steel framing workers working 5th floor while fireproof crews clean the area immediately below them).

2) Use of Scaffolding: There are several potential safety hazards within the fireproofing workers' process. Use of scaffolding could eliminate some of these risks, while also making potential productivity improvements.

D. Site Cleanup and Overcrowding

Most fundamentally, better clean-up on site could greatly improve safety conditions and reduce crew interference.

Again, if the work area were cleaner, the need for workers at our observation site would be almost totally alleviated. A sequential process with "clean as you go" procedures might make it possible for only one trade to work at that site at any given time. From the portion of recorded work (and from the general flow of work on that floor while surveyors were on site), it appears that there are more workers on site than are necessary. This is not possible to state conclusively without more extensive and lengthy observations.

E. Stock Yard & Parking Space

This site is suffering a lack of parking space for workers. They are currently using the open space as a lay down area for steel structural members. Partial pavement for parking space will provide clearness for construction site, also relieve the cost of cleaning the access road to the site.

VI. CONCLUSION

Beyond the potential short-term gains in an improved process, this case offers several key lessons in work sampling and productivity improvement:

Focus on the entire work process, not just the immediate task. Authors were initially perplexed regarding how to improve the workers' productivity. The key to improvement lay not in changing their task, but in looking at the structure of the entire work process. It is not necessary (or possible) to bring any one trade or individual task to 100% productivity. In fact, small-scale gains in a single task can actually detract from other tasks if management is not attentive to total-process improvement.

The productivity of various trades is strongly dependent on the organization of the work process and work site conditions. In this study, the steel framing workers appeared rather unproductive compared to the rate in other studies. The summary of the study are as following:

- From the Work Sampling Study, the steel framing workers' Labor Utilization Factor is 29.09 %.
- From the 5-Minute Rating Study, the observed workers' effectiveness is 74.67%.

In reality, they were simply completing a task in which their time and skills were not well organized. Looking at the Crew Balance charts, it is easy to attempt productivity improvement by eliminating all Individual Idle or Talking among peers. This quickly proves impossible micro-management for workers and managers. Providing the work crews with a well-planned process – better yet, allowing them to help develop the process – can improve morale, productivity, and individual initiative.

Herein lies one of the fundamental principles for improving any process: management must be willing to take risks. When project leaders are willing to be vulnerable and listen to their subordinates (even if they may not like what is said), they gain a far greater appreciation for the real barriers to productivity at the job site. Improving the productivity of the entire project is not possible until everyone on the project is committed to improvement.

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